UTILITY POLE ACCIDENT RATE PREDICTIVE MODEL AND COUNTERMEASURES

BY

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Statistics published by department of transportation indicates that hundreds of fatal accidents have occurred throughout the United States every year. Many of these accidents are involved utility poles in rural areas throughout the country, costing lives and damages estimated to be in the order of millions of dollars annually. Although extensive studies have been conducted by researchers concerning utility pole accidents, there are not sufficient findings to pinpoint and conclude the exact factors contributing to the utility pole accidents. However, improvement in roadway design and relocation of potentially dangerous utility poles have greatly influenced the reduction of the frequency of such fatal accidents. Therefore, more research is needed to clearly identify the primary and secondary factors and their roles in contribution to utility pole accidents; thus, an appropriate utility pole accident predictive model can be developed.

In order to achieve such a goal, the data collected from field and Florida Department of Transportation were sorted, organized, and refined for further analysis. The important factors contributing to the pole accidents were investigated and identified. As a result, the methods of statistical analysis were employed in order to establish any possible correlation among parameters and developed a utility pole accident rate predictive model which was validated against available utility pole accident data.

It is expected that the developed model will equip transportation agencies, especially Florida Department of Transportation, and utility companies with a better and more reliable tool to design safer roadways and to allocate the utility poles in such a way that minimizes the chance of pole accidents. Therefore, the overall benefit to society is saving many lives and a significant reduction in high cost of property damages and court settlements.

CHAPTER 1
INTRODUCTION

1.1 Problem Statement

Reducing the frequency of fatal accidents involving utility poles in rural roadways is a major problem which transportation agencies and utility companies are facing today. The absence of a sound method of identifying the crucial parameters contributing to the utility pole accidents allows disastrous consequences leading to the lose of lives, property damages and high costs of court settlements.

Tremendous amounts of resources have been devoted to research and development of methodologies which could clearly describe the nature and characteristics of utility pole accidents and lead to a reasonable solution. However, only a few models and methodologies have been proposed of which one or two have been adopted for practical purposes. These models are developed based on a data fitting method and are considered empirical formulas. As annual average daily traffic (ADT) increases, the empirical formulas lose their validities; therefore, some adjustments and modifications have to be made among the parameters (coefficients) in order to validate the models.

Since the parameters used in the model could also be interactive and/or correlated, it is necessary to conduct some appropriate test statistics in order to identify any interaction or correlation and power of contribution of each parameter on the predictive model. Thus, the existing empirical prediction formulas (models) for utility pole

accidents are unable to incorporate the interactions among the parameters (if any). As a result, the output information for identification of hazardous roadways is inadequate resulting in extra unnecessary expenses. It has been suggested that relocation of utility pole results in a significant reduction in utility pole accident frequency. Even though this seems reasonable, it is not a complete solution the utility pole accident problems.

An effective and economical pole relocation procedure demands a reasonable utility pole accident predictive model as well as consideration of associated tort liability. Although the elements of tort liability and predictive model are not the same, they must be consistent with Federal Highway Program Manual, section 6-6-3-2, and Florida Department of Transportation (FDPT) policy on utility pole locations.

The proposed research is the continuation of previous research on utility pole accidents conducted by the University of Florida and other agencies sponsored by the Florida Department of Transportation (FDOT) and the Federal Highway Administration (FHWA). The results of the previous studies are integrated and incorporated into a more comprehensive and in-depth study of vehicle-utility pole accidents presented here.

1.2 Research Objectives

The objective of this research is to make an in-depth investigation into the problem of utility pole accident frequency in the state of Florida. This requires an outline of the important tasks and procedures which must be followed in order to come out with a concrete and convincing answer to the minimization of pole accident rate in general and utility pole accidents in specific in the state of Florida.

The steps required to achieve the objectives of this research are given in a flow chart, shown in Figure 1.1. In addition, one should also consider the social, political, legal, and especially, economical effect on every step of the procedure, otherwise the outcome of the research would be inadequate and unreliable.

The scope of this research is limited to the urban and rural roadway utility pole accidents including Curb and Gutter. More over, it is possible to apply this methodology to any other types of roadways with some modifications if necessary. The effectiveness of parameters outlined earlier (ADT, speed limits, offset, pole density) will be the main focus of this research in analyzing the utility pole accident data obtained from FDOT.

The developed methodology and model will assist transportation agencies (i.e., FDOT) in planning and designing the safer roadways and utility companies in allocating the utility poles along the shoulders of roadways with minimum required offset based on FDOT Clear Zone Policy. The developed procedures will also help Department of Transportation (DOT) to answer the following critical questions.

1. What is the effect of each parameter used in the model in case any changes becomes necessary?

2. Which parameter(s) is the most important one to consider if any modification to the model is needed?

3. Which location is considered to be the most hazardous one (utility pole accident) and what recommendations are appropriate for this section?

4. Is it really correct to conclude that utility pole location is a major cause of pole accident or are there other factors such as geometry of the roadway which also contributing to such accidents?

1.3 Dissertation Organization

As it is shown in the research flow chart in Figure 1.1, there are six chapters in this dissertation. Chapter 1 provides a brief introduction to utility pole accidents. Chapter 2 reviews the previous works done on pole accidents and developed models. It also includes an extensive literature search on vehicle utility pole accidents.

Chapter 3 is a brief review of cost analysis and cost-effectiveness countermeasures used in utility pole accident rate predictive models. These methodologies are used frequently to correct the problem of pole hits by reducing the frequency of the pole accidents. Chapter 4 constitutes the heart of this dissertation where the variables of the model (pole density, vehicle speed, ADT, and pole offset) are identified and the mathematical relationship among these factors is derived. As a result, a flexible vehicle utility pole accident model could be developed using the method of Poisson's Regression Analysis, commonly used in accident rate prediction models. A model comparison is also made in order to identify limitations, advantages, and disadvantages for each existing model.

Chapter 5 concentrates on sensitivity analysis of the variables and their ranking with respect to their contribution to the vehicle utility pole accidents. Finally, Chapter 6 provides a summary, conclusion, and recommendations for future work pertaining to vehicle utility pole accidents.

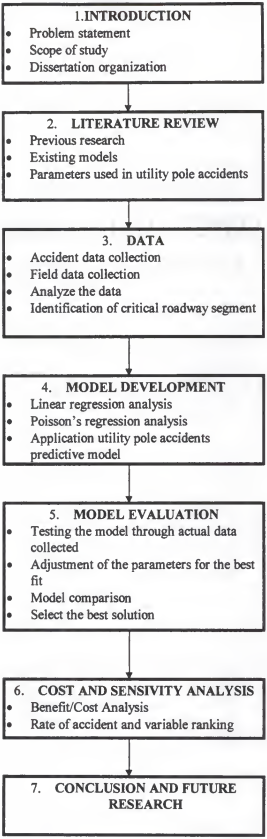


Figure 1.1: Research development flow chart.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Traffic Accident Research Activities

This chapter reviews the previous studies and research pertaining to vehicle-utility pole accident and the corresponding factors contributing to such accidents. These factors include pole offset, pole density, average annual daily traffic (ADT), vehicle speed, weather conditions, perception reaction time, and geometry and width of the roadway.

However, extensive research on utility pole accidents [46, 53, 87] revealed that the vehicle travel speed is one of the most crucial factors contributed to utility pole accidents. Even though, this finding is consistent with other related studies, it is almost impossible to estimate the travel speed of the vehicle accurately before hitting the pole.

The recent research [46] indicates that for very severe and limited cases of accidents, it is possible to predict the speed of the vehicle before the accident with utility pole. Thus, the complete statistical analysis concerning reconstruction of data for estimating the travel speed of a vehicle before crashing into utility pole is unavailable. As it is described later on, travel speed is not the only factor contributing to the pole accidents although the damage and severity of accidents involving utility poles are proportional to the speed of the vehicles. Previous research also indicates that factors such as pole offset, pole density, and annual average daily traffic (ADT) have greatly influenced the crashes involved vehicle-utility pole accidents and the damages left behind.

Fatal accidents involving utility poles account for a large percentage of total fatal accidents reported in State of Florida. According to the published report by NHTSA's Fatal Accident Report System (FARS) and FHWA's "Highway Statistics" from 1990 to 1994, the total number of pole accident fatalities in state of Florida is 365 which ranks 5^{th} in the number of utility pole fatalities and 18^{th} per 100 billion vehicle miles of travel nationwide.

In order to reduce the frequency of vehicle utility-pole accidents, the following countermeasure methods are suggested [69, 87]. These methods include:

- Relocation of utility pole by increasing the offset such that utility pole is Further away from the edge of roadway [77].
- Installation of underground utility lines, hence, eliminating the utility pole.
- Using breakaway poles, shown in Figure 2.1.
- Using protective device such as guardrails, described in Tables 2.1-2.2.
- Reduction in pole density.

Each countermeasure is tested individually and its benefits over cost evaluated using the available tables of pole accidents. The degree to which the rate of accidents is decreased is a measure to adopt or reject a particular countermeasure. The total benefit and cost of each countermeasure is evaluated using factor statistics (unit cost) published annually by National Highway Traffic Safety Administration (NHTSA).

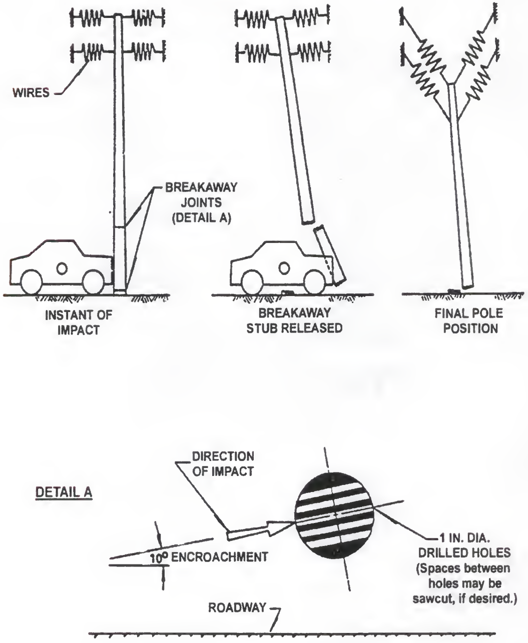


Figure 2.1: The "breakaway stub" and angle of encroachment [65].

Finally, the method of benefit/cost analysis is used in order to select the most economical countermeasure. The complete details of the method of benefit/cost analysis can be found in references [19, 40, 41, 54, 72, 75, 79].

Table 2.1: Maximum embankment height permitted without Guardrail for a slope of 2:1 [66].

AADT (vpd)	Embankment Height (ft)
250	40
500	31
1,000	24
2,000	20
3,000	18
4,000	17
5,000	16
Over 5,000	15

Table 2.2: Guardrail warrant criteria for fill embankments [81].

	AADT (vpd)			
	> 5000	751-5000	400-750	< 400
Slope	Slope Height (ft)			
1 ½ : 1	4	6	9	17
2 : 1	8	10	16	31
2 ½ : 1	12	16	25	49

Note : 1 ft = 0.305 m.

2.2 Existing Utility Pole Accidents Predictive Models

Before a decision is made to select a particular countermeasure, it is necessary to develop a mathematical model which will incorporate the variables outlined earlier and predict the frequency of accident based on available accident data. Extensive studies have been conducted concerning pole accidents by researchers and several statistical models

have been proposed of which four of the most common ones are introduced here. These models include:

- Zegeer's model
- Binomial distribution
- Negative binomial distribution
- Poisson distribution.

A description of each model, its parameters, variables, advantages, and disadvantages, are given in the following sections.

2.2.1 Zegeer's Model

Zegeer's utility pole accident predictive model is an empirical formula relating the rate of accident to the input variables, namely, annual average daily traffic (ADT), pole density, and pole offset. The model was obtained using regression analysis and parameters were estimated and adjusted to fit the data where a prediction of rate of accident could be made based on a given set of input variables. Zegeer's statistical model is:

$$F_{acc} = \frac{9.84 * 10^{-5}(ADT) + 0.0354(DEN)}{(OFF)^{0.6}} - 0.04$$

where

F_{acc} = Rate of accidents / mile / year
DEN = The number of utility poles per mile
OFF = Average utility pole offset (in feet)
ADT = Average annual daily traffic

Note: 1 m = 3.28 feet; 1km = 0.62 mile; 1 pole/km = 1.61 pole/mile
1 accident/mile/year = 0.62 accidents/km/year

According to Zegeer's model, it is clear that pole offset, pole density, and ADT are the most important independent variables influenced utility pole accidents and to be included in the model. The relationship between rate of accident , pole density, and ADT. is linear, whereas, the relationship between F_{acc} and pole offset is nonlinear making pole offset the most important and sensitive variable. One of the disadvantages of this model is its exclusion of speed limit or travel speed of the vehicle. Another disadvantage of Zegeer's model is that it can handle ADT up to 60,000 only. It is also important to mention that the model was developed in 1983 based on available utility pole accident data at that time.

Roadways also go through periodical changes such as addition of lanes, widening, extension, elevation, and other necessary geometric changes. In order to validate the model, it is very important to re-evaluate the existing models against the current available utility pole accident data and possibly make the necessary modifications or adjustments to the parameters.

However, this model gives an overall view of how the behavior of variables is with respect to the rate of accidents but fails to provide a complete picture of the utility pole accident problem. In addition, the data used to build Zegeer's model were obtained from four states other than Florida. Therefore, there might be significant differences in the nature of utility pole accidents that occurred in Florida and other states due to conditions of weather, driving habits, roadway geometry, etc. Thus, the proposed model under study uses the pole accident data obtained from Florida Department of Transportation (FDOT) for analysis and determination of model parameters.

2.2.2 Binomial Distribution

Binomial distribution is often used for repeated trials where the outcome is binary, namely, success or failure. Let n represent the number of trials and x the number of successes. In order to use binomial distribution, the following assumptions must be satisfied:

1. There are two possible outcomes for each trial, called " success" and " failure."
2. The probability of a success is the same for each trial.
3. The n trials are independent of each other
4. There are n trials where n is constant.

Thus, the probability of x successes in n trials is given by

$$P(x;n,p) = \frac{n!}{x!(n-x)!} p^x (1-p)^{n-x}, \qquad x = 0,1,\ldots,n$$

where p is probability of a success and (1- p) is probability of a failure.

Even though it is desirable to find the probability of hitting a pole for a given value of x , the value of p is not known in advance. Therefore, it is required to design and conduct a separate experiment for every roadway and find an estimate value of p which is not feasible practically.

In any case, one may use the recorded data available and calculate a rough estimate of p for trend analysis only. The method of binomial distribution is used extensively in the manufacturing process to detect and reduce the defective products. A complete and detailed account of binomial distribution and its applications are cited in references [31, 56, 64].

2.2.3 Negative Binomial Distribution

Negative Binomial or Pascal distribution is generally used in traffic related problems such as rate of accidents in a given segment or intersection of roadway when there is a variation of average volume traffic during each observation interval. To apply this method, it is assumed that observation interval and signal cycle coincides. Negative binomial distribution is stated as:

$P(x) = \dfrac{(k+x-1)!}{(k-1)!x!} p^k q^x$ where k is a positive integer, p is probability of success, and

$q = 1 - p$. Negative binomial distribution has been used in studies of Intersection Accident Frequencies in a report prepared for Transportation Research Board, Washington D.C., January, 1996 [64].

2.2.4 Poisson Distribution

The Poisson distribution is used to describe the completely random occurrence of discrete events. Thus, if traffic exhibits random behavior then it can be represented by the Poisson's distribution which is stated as:

$$P(x) = \frac{\mu^x e^{-\mu}}{x!} \quad , x = 0,1,\ldots,n \qquad \text{and} \qquad 0 < \mu < \infty$$

where μ is the average or mean value of the event x per observation. In the case of traffic, μ is defined as:

$\mu =$ total # of cars observed / Total # of observation period and $Variance = \sigma^2 = \mu$.

The application of Poisson distribution to traffic accidents is well established and explained in great detail in Chapter 4.

2.3 Miscellaneous Traffic Accident Predictive Models

In addition to the models described earlier, there are other accident predictive models which are important to the study of pole accidents and provide insight and a great deal of information pertaining to roadway cross section design and preventive measures. Two of the most recently developed models are described here. These models include:

- Zegeer's 2nd Model
- Hadi et al. Model

2.3.1 Zegeer's 2nd Model

In 1995, the study titled " Safety Effect of Cross Section Design for Two Lane Roads," using regression analysis resulted in developing the following model [89, 91]:

$$AO = 0.0019(ADT)^{0.8824}(0.8786)^{W}(0.9192)^{PA}(0.9316)^{UP}(1.2365)^{H}(0.8822)^{TER1}(1.3221)^{TER2}$$

where

AO = number of related crashes per mile (single-vehicle, sideswipe and head-on crashes);
W = lane width in feet;
PA = average paved shoulder width in feet;
UP = unpaved shoulder width in feet;
H = median roadside (or hazard) rating;
$TER1$ = 1 if flat, 0 otherwise; and
$TER2$ = 1 if mountainous, 0 otherwise.

According to the results obtained in this study, increasing the amount of lane widening resulted in a further increase in the percentage reduction in the related number of

crashes. For example, 1 foot (0.3m), 2 ft (0.6m), 3 ft (0.9m), and 4 ft (1.2m) lane widening between 8 and 12 ft (2.4 and 3.7m) resulted in 12%, 23%, 32%, and 40% reduction in related number of crashes, respectively. Moreover, for low traffic volume road ($ADT < 2000$ vpd), it was found that widening lane width from 10 ft (3.0m) to 11ft (3.4m) results in a significant decrease in the crash rates.

2.3.2 Hadi et al. Model

A comprehensive study [31] on State of Florida Traffic Accident Data using negative binomial regression resulted in a statistical model which is described below.

$$TA = \exp[-9.053 + 0.7212 \log(L) + 0.8869 \log(AADT) - 0.0435(LW) - 0.0262(SP) + 1145(IS) - 0.123(TS)]$$

where

TA	= Total accidents including fatality, injury, and property damage only (PDO), accident / mile / year;
L	= The length of highway segment;
$AADT$	= Annual average daily traffic volume;
LW	= Lane width in feet;
SP	= Posted speed limit (MPH) for the highway segment;
IS	= Number of intersections per mile;
TS	= Total shoulder width (UP+PS) in feet;
PS	= Paved shoulder;
UP	= Unpaved shoulder.

This model is relatively general although it does not include the pole offset and pole density as its input variables commonly used in other statistical models.

A summary of operational, geometric characteristics, and crash statistics for various highway types are gathered in Tables 2.3-2.6.

Table 2.3: Observed average crash frequencies per mile and crash rates (in parentheses) for each type of roadways [31].

Roadway Type	MVM	Mid-Block Crashes (Rate)	Mid-Block Injury Crashes (Rate)	Mid-Block Fatality Crashes (Rate)	Total Crashes (Rate)	Total Injury Crashes (Rate)	Total Fatality Crashes (rate)
Rural Two-lane Highways	5816.00	2845.25 (0.489)	1802.75 (0.310)	128.75 (0.022)	4766.75 (0.820)	3069.25 (0.528)	202.00 (0.035)
Urban Two-lane Highways	2576.48	2155.25 (0.837)	1267.25 (0.492)	36.25 (0.014)	5358.00 (2.080)	3116.50 (1.210)	69.00 (0.027)
Urban Four-lane Undivided Highways	846.34	1382.75 (1.634)	752.00 (0.889)	13.50 (0.016)	4161.00 (4.916)	2231.00 (2.636)	28.00 (0.033)
Rural Freeways	8444.02	2329.50 (0.276)	1448.00 (0.171)	93.00 (0.011)	2740.75 (0.325)	1702.75 (0.202)	107.25 (0.013)
Urban Four-lane freeways	4831.39	1728.25 (0.358)	946.25 (0.196)	35.50 (0.007)	2620.25 (0.542)	1468.25 (0.304)	51.00 (0.011)
Urban Six-lane Freeways	4896.63	2802.00 (0.572)	1526.00 (0.312)	35.50 (0.007)	3705.75 (0.757)	2039.25 (0.417)	43.25 (0.009)
Rural Four-lane Divided Highways	3590.25	1437.75 (0.400)	1920.75 (0.256)	51.50 (0.014)	3088.75 (0.860)	1986.50 (0.553)	288.25 (0.080)
Urban four-lane Divided Highways	10417.39	7934.25 (0.762)	4628.75 (0.444)	101.50 (0.010)	23324.0 (2.239)	13565.8 (1.302)	247.75 (0.024)
Urban Six-lane Divided Highways	5111.12	5763.50 (1.110)	3214.75 (0.629)	52.00 (0.010)	16495.8 (3.227)	9373.8 (1.834)	129.00 (0.025)

Note : 1 crash/MVM = 0.62 crashes/MVKM, 1 mile = 1.61 km.

Table 2.4: Summary of operational and geometric characteristics and crash statistics for rural two-lane highways [31].

Variable	Mean	Std. Dev.	Skew.	Min.	Max.	Percent Of Zero
Mid-Block Crashes	1.708	3.971	10.28	0	128	50.05
Mid-Block Injury Crashes	1.082	2.433	7.617	0	67	58.75
Mid-Block Fatality Crashes	0.077	0.368	10.45	0	11	93.79
Total Crashes	2.862	6.291	10.00	0	195	38.11
Total Injury Crashes	1.843	3.991	8.717	0	113	47.24
Total Fatality Crashes	0.121	0.476	10.09	0	15	90.62
Section Length (mile)	0.631	1.083	4.262	0.051	12.28	0
AADT	4138.2	2380.4	0.614	200	9992	0
Lane Width (ft)	11.545	0.879	-0.58	9	16	0.00
Number of Intersection	0.964	1.732	3.212	0	16	53.03
Number of Interchanges	0.001	0.035	26.21	0	1	99.82
Horizontal Curvature Length (ft)	0.953	1.794	3.161	0	21.53	64.56
Horizontal Curvature Degree	0.679	1.291	2.89	0	12	64.56
Outside Paved Shoulder Width (ft)	0.659	1.717	2.81	0	12	85.29
Outside Unpaved Shoulder Width (ft)	7.249	2.330	-0.55	0	12	1.67
Speed Limit (mph)	52.135	5.622	-1.84	35	55	0.00
Truck Factor (%)	2.167	2.111	2.276	1	9.9	0.00
Outside Shoulder Curb	-	-	-	-	-	98.45
Friction Course	-	-	-	-	-	66.57

Note : 1 mile = 1.61 km, 1 ft = 0.305 m, 1 mph = 1.61 km/h

Table 2.5: Summary of operational and geometric characteristics and crash statistics for rural freeways [31].

Variable	Mean	Std. Dev.	Skew.	Min.	Max.	Percent Of Zero
Mid-Block Crashes	7.413	9.607	2.963	0	87	13.27
Mid-Block Injury Crashes	4.608	6.205	2.758	0	57	20.45
Mid-Block Fatality Crashes	0.300	0.653	2.850	0	5	78.20
Total Crashes	8.722	11.038	2.549	0	102	11.38
Total Injury Crashes	5.419	7.136	2.658	0	67	17.58
Total Fatality Crashes	0.341	0.703	2.576	0	5	75.58
Section Length (mile)	0.774	0.831	2.018	0.051	4.987	0
AADT	23485	10949	0.833	5834	57560	0
Median Width (ft)	71.026	31.418	2.621	24	250	0
Lane Width (ft)	12.000	0	0	12	12	0
Number of Interchanges	0.117	0.287	2.474	0	2	83.61
Outside Paved Shoulder Width (ft)	9.883	1.269	-6.15	0	12	1.27
Outside Unpaved Shoulder Width (ft)	1.831	2.739	2.237	0	10	44.79
Inside Paved Shoulder Width (ft)	3.847	2.34	0.692	0	10	12.31
Inside Unpaved Shoulder Width (ft)	0.433	1.583	3.736	0	8	91.97
Median Type	4.000	0	0	4	4	0
Speed Limit (mph)	64.514	2.223	-4.63	45	65	0
Outside Shoulder Curb	-	-	-	-	-	98.73
Inside Shoulder Curb	-	-	-	-	-	100
Friction Course	-	-	-	-	-	40.02

Note : 1 mile = 1.61 km, 1 ft = 0.305 m, 1 mph = 1.61 km/h

Table 2.6: Summary of operational and geometric characteristics and crash statistics for rural four-lane divided highways [31].

Variable	Mean	Std. Dev.	Skew.	Min.	Max.	Percent Of Zero
Mid-Block Crashes	2.460	3.751	3.878	0	51	34.82
Mid-Block Injury Crashes	1.575	2.488	3.386	0	27	44.23
Mid-Block Fatality Crashes	0.088	0.326	4.471	0	4	92.21
Total Crashes	5.284	8.302	3.627	0	111	23.87
Total Injury Crashes	3.399	5.524	3.490	0	61	31.44
Total Fatality Crashes	0.493	0.543	0.798	0	5	55.22
Section Length (mile)	0.366	0.511	3.882	0.051	4.823	0
AADT	12357	7277.3	1.009	1145	39830	0
Median Width (ft)	34.479	12.601	-0.03	3	68	0
Lane Width (ft)	11.988	0.120	-12.6	9	12	0
Horizontal Curvature Length (ft)	0.113	0.213	3.616	0	2.332	62.06
Horizontal Curvature Degree	0.561	0.982	2.096	0	5.0	62.06
Outside Paved Shoulder Width (ft)	2.111	2.620	1.11	0	13	55.00
Outside Unpaved Shoulder Width (ft)	7.353	3.026	-0.77	0	12	2.57
Inside Paved Shoulder Width (ft)	0.217	0.759	3.74	0	6	91.45
Inside Unpaved Shoulder Width (ft)	0.105	0.551	7.661	0	8	95.47
Median Type (ft)	4.083	0.668	0.041	2	6	0
Speed Limit (mph)	51.544	0.746	-1.53	25	55	0
Outside Shoulder Curb	-	-	-	-	-	88.88
Inside Shoulder Curb	-	-	-	-	-	95.94
Friction Course	-	-	-	-	-	41.96

Note : 1 mile = 1.61 km, 1 ft = 0.305 m, 1 mph = 1.61 km/h

2.4 Vehicle Travel Speed and Perception-Reaction Time

Literature review indicates that there is a significant correlation between perception reaction time and vehicle travel speed. Perception reaction time (PRT) is defined as the time to perceive the need for a response and initiate an action [46].

Another important factor to be considered in highway design criterion is sight distance (SD). Sight distance is defined as a distance a driver must be able to see in order to have enough time to make a necessary driving maneuver [46]. The components of sight distance include:

- Perception-Reaction time
- Maneuver time.

Maneuver time is the time to execute the driving response, once initiated [46]. Experimental results recorded in FHWA-RD-93-168 also indicates that PRT is greatly influenced by advancing age and ranges from 1.4-2.5 seconds as illustrated in Table 7. The values of risk distance vs. PRT for different travel speeds are given in Tables 2.8 and 2.9.

In conjunction with the definition of sight distance, stopping sight distance (SSD) is defined as the minimum sight distance required for a vehicle traveling at or near design speed to stop before reaching a stationary object in its path (AASHTO). Stopping sight distance consists of two components, namely, brake-reaction distance and breaking distance (travel distance from the moment brake applied until vehicle stops completely). Moreover, SSD is computed using the following mathematical equation [46]:

$$d = 1.47PV + \frac{V^2}{30(f \pm G)}$$

where

d = stopping sight distance (ft),

P = brake reaction time (s),

V = vehicle design speed (mi/h),

f = coefficient of friction between tires and roadways, and

G = grade (100%)

As it is seen in the above formula, d is a quadratic function of designed speed (V), an indication that the speed of the vehicle is the most important factor contributing to vehicle crashes. The values of SSD vs. different values of design speed are given in Table 2.10.

Table 2.7: Mean PRT by site, age, and day/night condition [46].

	DAY PRT (s)			NIGHT PRT (s)		
	Age Group			Age Group		
Site	20-40	65-69	70+	20-40	65-69	70+
1. Freeway lane Drop	4.05	4.27	5.72	3.73	4.21	5.97
2. Freeway lane Drop	6.56	4.35	5.41	4.44	5.02	4.26
3. Arterial Turn Lane	2.76	2.46	3.57	3.28	3.74	3.79
4. Arterial Turn Lane	2.68	6.01	4.42	4.29	3.57	3.90
5. Arterial Turn Lane	1.60	2.53	2.88	2.41	2.39	2.98
6. Complex Intersection	2.83	2.51	3.71	2.56	3.10	4.83
7. Freeway lane Drop	2.16	3.12	3.02	3.07	2.80	2.49
8. Freeway lane Drop	2.88	6.64	4.51	5.63	4.90	5.35
9. Freeway lane Drop	4.30	6.28	6.31	3.80	4.85	4.39
11. Arterial Turn Lane	2.05	3.38	4.78	3.63	3.54	2.84
12. Arterial Turn Lane	2.52	6.27	6.99	2.75	2.20	2.59

Table 2.8: Travel speed and risk distance (RD) for various brake reaction time in lab test [46].

Travel Speed (mph)	Median RD (feet) (PRT = 0.65 sec.)	Avg. RD (feet) (PRT = 0.75 sec.)	95 Percentile RD (feet) (PRT = 1.25 sec.)
35	33.87	38.5	61.6
40	38.72	44.0	70.4
45	43.56	49.5	79.2
50	48.40	55.0	88.0
55	53.24	60.5	96.8
60	58.08	66.0	105.6
65	62.92	71.5	114.4
70	67.76	77.0	123.2
75	72.60	82.5	132.0
80	77.44	88.0	140.8
85	82.28	93.5	149.6

Table 2.9: Relationship between travel speed and risk distance (RD) [46].

Travel Speed (mph)	Lower Bound of RD (feet) (PRT = 1.4 s)	Avg. RD (feet) (PRT = 2.0 sec.)	Upper bound of RD (feet) (PRT = 2.5 s)
35	71.9	102.7	128.3
40	82.1	117.3	146.7
45	92.4	132.0	165.0
50	102.7	146.7	183.3
55	112.9	161.3	201.7
60	123.2	176.0	220.0
65	133.5	190.7	238.3
70	143.7	205.3	256.7
75	154.0	220.0	275.0
80	164.3	234.7	293.3
85	174.5	249.3	311.7

Table 2.10: AASHTO stopping distance standards [2].

Design Speed mi / h (km/h)*	Assumed Speed for Condition mi / h (km/h)*	Stopping Sight Distance	
		Computed ft (m)*	Rounded for Design ft (m)*
20 (32)	20-20 (32-32)	106.7-106.7 (32.5-32.5)	125-125 (38-38)
25 (40)	24-25 (37-40)	138.5-146.5 (42.2-44.7)	150-150 (46-46)
30 (48)	28-30 (45-48)	177.3-195.7 (54.1-59.7)	200-200 (61-61)
35 (56)	32-35 (52-56)	217.7-248.8 (66.4-75.9)	225-250 (69-76)
40 (65)	36-40 (58-65)	267.0-313.3 (81.4-95.6)	275-325 (84-99)
45 (72)	40-45 (65-72)	318.7-382.7 (97.2-116.7)	325-400 (99-122)
50 (81)	44-50 (71-81)	376.4-461.1 (114.8-140.6)	400-475 (122-145)
55 (89)	48-55 (77-89)	432.0-537.8 (131.8-164.0)	450-550 (137-168)
60 (97)	52-60 (84-97)	501.5-633.8 (153.0-193.3)	525-650 (160-198)
65 (105)	55-65 (89-105)	549.4-724.0 (167.6-220.8)	550-725 (168-221)
70 (113)	58-70 (93-113)	613.1-840.0 (187.0-256.2)	625-850 (191-259)

*km = mi x 1.609 , m = ft / 3.28

2.5 Roadside Design Guide and State of Florida Clear Zone Policy

Florida Department of Transportation (FDOT) " Utility Accommodation Guide" outlines a set of rules and regulations which dictate the location of utility poles on the edges of roadways. According to these guidelines, utility poles can not be located at the median and they must be located at least five feet from the shoulder of the roadway.

However, greater need for transportation and an increasing number of vehicles require higher safety standards and occasional policy revision, especially in the rural areas with a larger number of utility poles. The main goal of this policy is to provide higher safety measures and reduce the annual frequency of utility pole accidents, lose of life, and extensive property damages. A summary of clear zone policy is given in Table C.1.

Table 2.11: Crash reduction factors due to increasing roadside clear recovery distance [31].

Amount of Increased Roadside Recovery Distance (feet)	Reduction in Related Crashes (%)
5	13
8	21
10	25
12	29
15	35
20	44

Table 2.12: Minimum clear zone distance needed without the installation of Guardrail [66].

ADT (vpd)	Clear Zone Distance (ft)		
	Traffic Speed (mph)		
	40	50	60
250	**	3	12
500	**	9	16
1,000	5	13	19
2,000	9	16	21
3,000	11	18	22
4,000	13	18	22
5,000	14	29	23
Over 5000	15	20	23

Note: 1 mph = 1.61 km/h, 1 ft = 0.305 m.

CHAPTER 3
COST ANALYSIS

3.1 Methods of Cost Analysis

The methods of cost analysis are applied to almost any problem which involves money in one way or the other. For example, cost evaluation and estimation is used as a routine process in construction, maintenance, and public work engineering. Therefore, it is very crucial to identify the appropriate method which works best for a particular application. In this chapter, several methods of cost analysis are discussed briefly including their advantages and disadvantages (limitations) in the following sections. These methods include:

1. Present worth method for comparing alternatives
2. Equivalent uniform annual series of payment method for comparing alternative
3. Future worth method for comparing alternatives
4. Rate of return method (ROR)
5. Incremental rate of return (IROR)
6. Benefit-Cost analysis

3.1.1 Present Worth Method for Comparing Alternatives

The method of present worth analysis is generally used to compare mutually exclusive alternatives and assess the combination of the benefits and costs of each one in order to select the optimum alternative. The time period for this method of analysis is a

very important parameter and requires careful consideration when it is used in the mathematical equation of present worth analysis.

If the useful life of each alternative equals the analysis period, then the method of present worth analysis is very straightforward to apply. If the useful life of at least two alternatives are different, it is necessary to convert all alternative useful lives to a common useful life such that each alternative period of analysis (useful life) divides this common period by a factor of a positive integer. For example, if alternatives A, B, and C have 5, 10, and 15 years useful life, respectively, then the common period of analysis should be 30 years.

3.1.2 Equivalent Uniform Annual Series of Payments Method

In annual cash flow analysis, the goal is to convert all benefits (incomes) and costs to an equivalent uniform annual series of benefits and costs; therefore, all the present worths are converted to a series of equivalent uniform end-of-period cash flows. Like the first method, annual cash flow analysis focuses on maximizing equivalent uniform annual benefits (EUAB).

Compared to the present worth method, annual cash flow involves fewer computations and provides the necessary information to calculate, for example, the toll rate for vehicles using toll bridge in shorter time. This method is commonly used in engineering constructions to estimate annual maintenance and financing costs of projects such as buildings, bridges, and roadway designs.

3.1.3 Future Worth Method of Comparing Alternatives

Future worth method is used to predict the growth of any quantity at a given rate. This quantity can be money, population, or goods. One of the main advantages of this method of analysis is that it provides the necessary information in order to make an appropriate decision with regard to a specific issue such as accommodation of future growth of population. Future worth method of analysis assumes that all the life cycles of alternatives are identical in length and the comparison must be made at a common future date. The only difficulty encountered with this method is that the changes in market place may influence the estimated growth significantly resulting incorrect prediction.

3.1.4 Rate of Return Method (ROR)

Rate of return is defined as the interest rate at which the costs and benefits are equal to each other. The procedures concerning this method are different from the methods described earlier since it is required to find the interest rate at which total benefits is equal to total costs for the period of analysis or life cycle of alternatives. Generally speaking, the higher rate of return is desirable for selecting the best alternatives.

However, in some cases, the larger value of ROR may not be the sole measure of making a decision for selecting an alternative. Computations involved in this method are straightforward requiring the knowledge of interpolation for estimating the rate of return at which total costs and benefits are equal. The equations for calculating ROR are:

- PW of benefits - PW of costs = 0
- (PW of benefits) / (PW of costs) = 1
- Net present worth = 0

- EUAB - EUAC = 0
- PW of costs = PW of benefits

3.1.5 Incremental Rate of Return (IROR)

As it was mentioned earlier, a high rate of return may not be the sole measure in selecting an alternative. Therefore, the concept of Incremental Rate of Return is used to resolve the deficiency encountered with rate of return in choosing the best alternative. Incremental rate of return and rate of return share the same principles but the former uses the concept of increment in benefit for each additional dollar value while the latter one analyzes each alternative benefit-cost ratio individually.

To calculate IROR, one may apply the method of interpolation or use available tables of interest rate. In any case, the value of IROR is an estimated one requiring its value to be checked against Minimum Attractive Rate of Return (MARR) defined as the highest cost of borrowed money, cost of capital, or opportunity cost.

3.1.6 Benefit-Cost Ratio Analysis

Benefit-cost ratio is the most common method of cost analysis used in engineering, sciences, and almost all government projects. The basic principle of this method is that all benefits and costs are calculated separately using any of the first three methods of analysis described earlier (identical method for both, benefit and cost) and then take the ratio of benefit to corresponding cost. This value is called B/C ratio which must be greater than one for each alternative to be considered for further analysis and decision making. Like rate of return method, B/C method has some difficulties in identifying the best choice

among the alternatives using the B/C ratio. For example, even though higher value of B/C is desirable, it is not always true that higher B/C for an alternative means the better choice.

Therefore, to overcome this problem, the concept of Incremental Benefit-Cost ratio is (IBCR) introduced here. Based on this method, the difference of two alternative benefits divided to the difference of their corresponding costs to get IBCR. If this value is greater than one select the alternative with higher cost, otherwise the one with lower cost.

However, none of these methods consider the selection of the optimum choice, a balance between cost and quality, since it was assumed that all the alternatives under consideration provide the same quality job. It is well known that quality and cost are directly proportional to each other meaning that a higher quality product demands higher cost to manufacturer and consumer.

To clarify and better understand the advantage of using IBCR over BCR method in selecting the best alternative, one may refer to the following example which consists of four alternatives, namely, A, B, C, and D. According to Table 3.1, the best choice is alternative B using BCR method. The Incremental benefit-cost ratio for these alternative are given in Table 3.2. Based on this Table, the best alternative is A. Had we have used the BCR conclusion rather than that for IBCR there would have been an incorrect selection of alternative which resulted in higher cost and less benefit. To demonstrate that the alternative chosen is the one that will maximize the equivalent benefit less the equivalent costs, Table 3.3 presents this net figure for each alternative.

Table 3.1: Benefit-Cost ratios on total investment for four alternatives.

Alternative	Equivalent Annual Benefits	Equivalent Annual Cost	B-C Ratio
A	$180,000	$91,000	1.98
B	168,000	80,000	2.10*
C	114,000	78,000	1.46
D	95,000	50,000	1.90

* Alternative B is considered the best choice.

Table 3.2: Incremental Benefit-Cost ratios.

Alternative	Incremental Annual Benefits	Incremental Annual Cost	Incremental B-C Ratio	Decision
A-Null	$180,000	$91,000	1.98	Select A
B-A	12,000	11,000	1.09	Reject B
C-A	66,000	13,000	5.08	Reject C
D-A	85,000	41,000	2.07	Select A*

* Alternative A is considered the best choice.

Table 3.3: Benefits less Costs for four alternatives.

Alternative	Equivalent Annual Benefits	Equivalent Annual Cost	Net Improvement of General Welfare
A	$180,000	$91,000	$ 89,000
B	168,000	80,000	88,000
C	114,000	78,000	36,000
D	95,000	50,000	45,000

3.2 Vehicle Utility Pole Accident Cost-Effectiveness Countermeasures

Some of the countermeasures used as alternatives to utility pole accident problems were described in chapter 2. [88]. The main purposes of these countermeasure are to reduce the frequency of utility pole accidents and to provide more safety measures on rural and urban roadways. Since adoption of any countermeasure involves cost, it is extremely important to evaluate and assess the benefit and cost of each countermeasure and make sure that it meets the requirements and fulfils the expectations.

Thus, the method of Incremental benefit-cost analysis is employed in order to select the best countermeasure alternative available. In addition, other considerations should be taken into account if two countermeasures are differentiated by a very small margin. Finally, a countermeasure with highest benefits is selected and implemented. The estimated cost of different countermeasures and materials is given in Table 3.4.

Table 3.4: Summary of total cost for each countermeasure based on a single pole hit/year.

Action	Initial Cost	Maintenance Cost Average (Annually)	Potential Liability	Total 10 year Cost (Average)
None	0	$3,000	$ 1m	$30,000
Breakaway (AD-IV)	$2500-$3,300	$800	0	$10,900
Guardrail (ET-2000)	$2300-$3,700	$1,500	0	$13,000
Relocate Pole	$3,500 -$17,000	0	0	$10,250
Crash Cushion (ADIEM)	$4000-$6,000	$1,500	0	$20,000
Concrete (LPB)	$1,500-$2,500	$300	0	$5,000

CHAPTER 4
DEVELOPMENT OF UTILITY POLE ACCIDENT RATE PREDICTIVE MODEL

4.1 Introduction

Considerable efforts have been devoted to the development of countermeasure methods in order to minimize or reduce accidents involved fixed objects of which utility pole accidents accounts about 5% of the total nationwide accidents. Statistics also indicates that more than 5% of the nationwide traffic fatalities and more than 15% of the deaths involved fixed object accidents are due to utility accidents [23]. In 1980, a report by National Highway Traffic Safety Administration indicates that 1,840 of 10,329 fatal fixed object accidents (19.8%) involved utility pole hits. In 1980, a comprehensive study [32] revealed that 21.1% of the 8,000 single vehicle accidents, fixed object accidents in urban and suburban, involved utility pole accidents. In this particular case, the density of poles was found to be the single most important factor in predicting utility pole accidents.

This situation does not contradict the previous finding of pole offset to be the most important parameter contributing to utility pole accidents if the pole offsets were relatively large and far from the edge of the roadway. In addition, factors such as speed limit, average daily traffic, roadway design, and road width were also found to have great influence on utility pole accidents [32].

Statistics published by the National Summary of Utility Pole Fatalities indicates that Florida ranks 16th in terms of number of fatalities, 1990 to 1993, per 100 billion

vehicle miles of travel. For example, the total number of fatalities involved utility pole accidents is 5,009 nationwide of which state of Florida accounts for almost 5.9% (a total of 297) fatalities [21]. In order to minimize or reduce the severity and frequency of utility pole accidents, pioneers [88] suggested that the research efforts should be focussed toward cost-effectiveness analysis where the effects of pole offset, pole density, and annual average daily traffic (ADT) on utility pole accidents are fully investigated. As a results of previous studies [87], some possible countermeasure alternatives were suggested in order to minimize or reduce the frequency and severity of utility pole accidents. These alternatives are as follow:

- Locating utility pole lines underground
- Increasing the lateral offset of poles
- Protective devices
- Reducing the number of poles
- Utility breakaway poles
- Other countermeasures

In addition to the factors contributing to the utility pole accidents mentioned earlier, travel speed of the vehicle was found to have very significant effect on the severity of accidents. The effect of travel speed on traffic accidents has been extensively investigated [22, 49, 70] and the results confirmed the direct relationship between travel speed and severity of accident. Since it is almost impossible to estimate the travel speed of vehicle accurately right before the accident, the developed models so far lack this important parameter. Increasing the number of utility pole accidents and severity of such accidents demands an in-depth study and research in order to develop a mathematical

model which reasonably and accurately predict the number of utility pole accidents or probability of such accidents for rural roadways.

The purpose of this chapter is to apply available statistical analysis methods such as Poisson regression and probability distribution to utility pole accident data in order to formulate the utility pole accident rate predictive model based on independent variables, namely, pole offset, pole density, ADT, and posted speed. The complete details and discussions of the methodologies are given in the following sections.

4.2 Linear Regression Analysis

4.2.1 Introduction

Regression analysis is a statistical tool used to relate a dependent variable (Y) to the independent variables ($x_1, x_2, x_3, \ldots, x_n$) for modeling purposes. The independent variables could be quantitative, qualitative, or mixture of both types. The procedures in using quantitative and qualitative variables are different although the principle is the same. The simplest form of regression is the one with only one independent variable (x) and dependent variable (Y). The main advantages of employing the method of regression analysis are flexibility and applicability to many problems in the field of engineering, natural sciences, economics, biological sciences, and social sciences.

Depending on the particular problem, it is necessary to investigate for an appropriate model (i.e., straight line, log function, parabola, or polynomial functions) which best describe the problem and produces a reasonable estimate of the output for a given set of independent input variables.

Identifying the appropriate model is a necessary step toward using regression analysis but not sufficient one unless the best-fitting model is determined. For example, if a model is a straight line, how the best fitting straight line is selected?. This chapter concentrates on modeling utility pole accidents using Poisson regression analysis.

4.2.2 Single Variable Regression Model

As it was mentioned earlier, regression analysis is a statistical technique which relates one or several independent variables ($x_1, x_2, x_3, \ldots, x_n$) to a dependent variable (Y). The simplest form of regression model is a straight line regression of the form:

$$Y = \beta_0 + \beta_1 x + \varepsilon \tag{4.1}$$

where β_0 and β_1 are constants to be estimated and Y is dependent variable on a single independent variable x. Before trying to find the best fitted straight line, it is important to indicate all the assumptions made for straight line regression model. These assumptions are as follow.

1. Independence: The values of dependent variable (Y) are statistically independent of each other. Although this assumption may not be as strong as the others follow, it is a reasonable assumption in many applications.
2. Normal distribution: Dependent variable (Y) has a normal distribution for any fixed value of x. This assumption is required in order to test the hypothesis and evaluate the statistical significance.
3. Linearity: The mean value of random variable Y ($\mu_{Y|x}$) is a straight line function of independent variable x as is given in equations (4.2) and (4.3).

$$\mu_{Y|x} = \beta_0 + \beta_1 x \tag{4.2}$$

or

$$Y = \beta_0 + \beta_1 x + \varepsilon \tag{4.3}$$

where ε is a random variable with mean zero at fixed value of x (i.e., $\mu_{\varepsilon|x} = 0$ for any value of x). The error (ε) is given in equations (4.4) and (4.5).

$$\varepsilon = Y - (\beta_0 + \beta_1 x) \tag{4.4}$$

or

$$\varepsilon = Y - \mu_{Y|x} \tag{4.5}$$

Error (ε) is an important factor in considering the best fitting line since its value indicates the adequacy and accuracy of the proposed model. Therefore, it is desirable to have error as small as possible which may not be attainable in every model.

4. Homoscedasticity: The variance of Y is the same for any x. Mathematically, this means that:

$$\sigma^2_{Y|x} = \sigma^2 \qquad \text{for all } x.$$

Like Y, ε is also a random variable and x is not a random variable. β_0 and β_1 are called parameters to be estimated using least square method. Since the error is not observable, it is possible to compute the point estimates $\hat{\beta}_0$ and $\hat{\beta}_1$ of β_0 and β_1, respectively, and determine the point prediction of error ($\hat{\varepsilon}$) at a given value of x.

$$\hat{\varepsilon} = Y - \hat{Y} = Y - (\hat{\beta}_0 + \hat{\beta}_1 x)$$

where $\hat{Y}$ is predicted response of Y and $\hat{\varepsilon}$ is called residual. In general , for n pairs of

points (x_i, Y_i), residuals is as follow:

$$\hat{\varepsilon}_i = Y_i - \hat{Y}_i = Y_i - (\hat{\beta}_0 + \hat{\beta}_1 x_i)\ ,\ \ i = 1, 2, 3, \ldots, n$$

4.2.2.1 Determination of the best fitted straight line

The next step after deciding about straight line regression is to determine the best fitted straight line for our model. To achieve this, one may use the commonly analytical approaches listed below.

- The least square method
- The maximum likelihood

The first method will be discussed in this section. The method of maximum likelihood will be explained in Poisson regression section where its importance becomes more apparent.

4.2.2.2 The least- square method

This approach is based on finding the straight line, among infinitely many, which minimizes the sum of squared residuals, vertical distances from data points to the line. Hence, the equation $\hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i$ gives the predicted output value at x_i where $\hat{\beta}_0$ and $\hat{\beta}_1$ are estimated values of β_0 and β_1, intercept and slope, respectively. The vertical distances from the data points to the line and their corresponding sum of squares are given in equations (4.6) and (4.7).

$$d_i = \left|Y_i - \hat{Y}_i\right|, \quad i = 1, 2, 3, \ldots, n$$

or

$$d_i = \left|Y_i - (\hat{\beta}_0 + \hat{\beta}_1 x_i)\right| \qquad (4.6)$$

$$\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2 = \sum_{i=1}^{n}(Y_i - (\hat{\beta}_0 + \hat{\beta}_1 x_i))^2 \tag{4.7}$$

Additionally, It is required to estimate β_0 and β_1 such that the summation given by equation (4.7) has the minimum value, called the residual sum of squares or sum of squares due to error (SSE). Another word, we want to have the following inequality satisfied for any other choices of β_0 and β_1 (i.e., $\overline{\beta}_0$ and $\overline{\beta}_1$).

$$SSE = \sum_{i=1}^{n}(Y_i - (\hat{\beta}_0 + \hat{\beta}_1 x_i))^2 \leq \sum_{i=1}^{n}(Y_i - (\overline{\beta}_0 + \overline{\beta}_1 x_i))^2$$

Mathematical formulas for estimating the values of parameters β_0 and β_1 are given as follow:

$$\hat{\beta}_1 = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(Y_i - \overline{Y})}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \tag{4.8}$$

and

$$\hat{\beta}_0 = \overline{Y} - \hat{\beta}_1 \overline{x} \tag{4.9}$$

where

$\overline{x}$ is the mean of the x's values and $\overline{Y}$ is the mean of the Y's values. Hence, the least square straight line is represented by

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 x \tag{4.10}$$

Substitution $\hat{\beta}_0$ from (4.9) into (4.10) results in an equivalent equation which relates the estimated value of Y ($\hat{Y}$) to the average values of Y and x.

$$\hat{Y} = \bar{Y} + \hat{\beta}_1 (x - \bar{x}) \tag{4.11}$$

It was mentioned earlier that SSE is a measure in which determines the goodness of the fitting straight line. The smaller SSE the better the fitted line. Hence, it is important to investigate the factors contributing to the SSE value. Large variation among the data points is a possible source of obtaining the large value for SSE. Another possibility is that the choice of straight line for our model may not be an appropriate choice for a given set of data points. Assuming the straight line model is an appropriate one, we can make an estimate of σ^2 (S^2) using SSE.

$$S^2_{Y/x} = \frac{1}{n-2}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2 = \frac{SSE}{n-2} \tag{4.12}$$

where n - 2 is the degrees of freedom of error term since there are only two parameters (β_0 and β_1) which estimate $\hat{Y}_i$ from n observations. In this case $\hat{Y}_i = \hat{\beta}_0 + \hat{\beta}_1 x_i$ is an estimate of the population mean response, $\mu_{Y|x}$, which varies with x. In order to evaluate the goodness of the best fitted line in predicting the value of Y for a given $\hat{Y}_i$, it is necessary to conduct some statistical testing hypothesis about parameters used in the model. The assumptions are made that variable Y, $\hat{\beta}_0$, and $\hat{\beta}_1$ have normal distribution.

These estimators and their corresponding variances are used to construct confidence interval and perform statistical testing using t-test distribution. The formulas and testing procedures for hypothesis are as follow.

Test statistic for slope (β_1) is:

$$t = \frac{(\hat{\beta}_1 - \beta_1^*)}{S_{\hat{\beta}_1}} \tag{4.13}$$

where $S_{\hat{\beta}_1} = \dfrac{S_{Y/x}}{\sqrt{S_{xx}}}$, $S_{xx} = \sum(x_i - \bar{x})^2$, and β_1^* is a prescribed value for β_1. This test statistic is used to test the significance of hypothesis H$_0$: $\beta_1 = \beta_1^*$ or H$_a$: $\beta_1 \neq \beta_1^*$. The residual (error) mean square ($S^2_{Y|x}$), an estimate to the true variance (σ^2), is calculated using equation (4.12). The value of $S_{\hat{\beta}_1}$ is an estimate of unknown standard error of $\hat{\beta}_1$, given by

$$\sigma_{\hat{\beta}_1} = \frac{\sigma}{\sqrt{S_{xx}}}$$

In a similar way, the formulas and hypothesis for testing intercept, β_0, are:

Test statistic for slope (β_0) is:

$$t = (\hat{\beta}_0 - \beta_0^*) / [S_{Y|x} (\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}})^{1/2}] \tag{4.14}$$

with $(n - 2)$ degrees of freedom , due to $S_{Y|x}$, and t distribution. The true unknown standard error of $\hat{\beta}_0$ is given as:

$$\sigma_{\hat{\beta}_0} = \sigma (\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}})^{1/2}$$

Since the value of true standard deviation (σ) is not available, the sample standard deviation, $S_{Y|x}$, is used to evaluate the value of test statistics in order to test the hypothesis. The following conditions enable us to reject null hypothesis (H$_0$) at a given significance level of α. Reject Ho at α-level if any of the following is true.

$| t | \geq t_{n-2,\ 1-\alpha/2}$ for two-sided test $\quad$ H_a: $\beta_o \neq \beta_0^*$

H_a: $\beta_1 \neq \beta_1^*$

$t > t_{n-2,\ 1-\alpha}$ for an upper one sided-test $\quad$ H_a: $\beta_o > \beta_o^*$

H_a: $\beta_1 > \beta_1^*$

$t \leq -t_{n-2,\ 1-\alpha}$ for a lower one sided-test $\quad$ H_a: $\beta_o < \beta_o^*$

H_a: $\beta_1 < \beta_1^*$

The values of $t_{n-2,\ 1-\alpha/2}$ and $t_{n-2,\ 1-\alpha}$ are tabulated as t-distribution table and are readily available in any statistical textbook. The following discussion is devoted to the interpretation of hypothesis testing involving intercept, β_o , and slope, β_1 .

4.2.2.3 Test for zero intercept (β_o = 0) and zero slope (β_1 = 0)

If hypothesis H_0: $\beta_o = 0$ is not rejected then fitted straight line is passing through the origin. This means that points were collected near zero values which have no physical significance. However, the interpretation is very different for rejecting or not rejecting H_0: $\beta_1 = 0$. If $\beta_1 = 0$ then the mean response does not depend on x or the test for H_0: $\beta_1 = 0$ may not be significant to a large residual SS, which may be caused by fitting the wrong model. If hypothesis H_0: $\beta_1 = 0$ is rejected, then one of the following cases is true.

Case 1: $\quad$ $\hat{Y} = \bar{Y} + \hat{\beta}_1 (x - \bar{x})$

which provides significant information for predicting Y at a given x.

Case 2:

In addition to the linear equation $\hat{Y} = \bar{Y} + \hat{\beta}_1 (x - \bar{x})$, there might be a need for additional term(s) such as curvilinear term.

In summary, the straight line model is easy to construct and estimate the parameters but it may not be the most adequate model describing the real relationship between x and Y values, therefore, other alternatives should be considered.

4.2.2.4 Inferences about the regression line $\mu_{Y|x} = \beta_0 + \beta_1 x$

Previous section was devoted to inferences about intercept and slope of the best fitted straight line. Moreover, it is possible to set up statistical test about the regression line where a confidence interval for $\mu_{Y|x_0}$ at $x = x_0$ is constructed. Hence, the hypothesis Ho: $\mu_{Y|x_0} = \mu^{*}_{Y|x_0}$ is being tested where $\mu^{*}_{Y|x_0}$ is some prescribed value. Procedures and formulas concerning testing the regression line are as follow.

Test statistic for $\mu_{Y|x}$ is:
$$t = \frac{\hat{Y}_{x_0} - \mu^{*}_{Y|x_0}}{S_{\hat{Y}_{x_0}}} \tag{4.15}$$

where
$$S_{\hat{Y}_{x_0}} = S_{Y|x}\sqrt{\frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}} \tag{4.16}$$

and $S_{\hat{Y}_{x_0}}$ is an estimate of the standard error of $\hat{Y}_{x_0}$ given by

$$\sigma_{\hat{Y}_{x_0}} = \sigma\sqrt{\frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}}$$

since
$$\hat{\beta}_0 = \bar{Y} - \hat{\beta}_1 \bar{x}$$

$$\hat{Y}_{x_0} = \hat{\beta}_0 + \hat{\beta}_1 x_0 = \bar{Y} + \hat{\beta}_1 (x_0 - \bar{x})$$

This test statistic under Ho has t-distribution with (n-2) degrees of freedom. The confidence interval for $\mu_{Y|x_0}$ at $x = x_0$ is:

$$\hat{Y}_{x_0} \pm (t_{n-2,1-\alpha/2}) S_{\hat{Y}_{x_0}} \tag{4.17}$$

The usefulness of confidence interval is due to the fact that to test hypothesis Ho: $\mu_{Y|x_0} = \mu^*_{Y|x_0}$, one needs to examine the confidence interval if it includes the value of $\mu^*_{Y|x_0}$ or not. If it does include $\mu^*_{Y|x_0}$, we do not reject H_0, otherwise we reject H_0 hypothesis. In addition, the equation $\hat{Y}_{x_0} = \hat{\beta}_0 + \hat{\beta}_1 x_0$ is a point estimate for the mean response $\mu_{Y|x_0}$ at $x = x_0$. In addition, prediction interval for Y is formulated as follow.

$$\bar{Y} + \hat{\beta}_1 (x_0 - \bar{x}) \pm t_{n-2,1-\frac{\alpha}{2}} S_{Y|x} \sqrt{1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}} \tag{4.18}$$

It should be noted that prediction interval is larger than confidence interval. To examine the errors associated with prediction interval, it is convenient to write the error of prediction at x_0 of $Y - \hat{Y}_{x_0}$ where Y is a new response value at x_0 in the following form:

$$(Y - \hat{Y}_{x_0}) = (Y - \mu_{Y|x}) + (\mu_{Y|x} - \hat{Y}_{x_0}) \tag{4.19}$$

(1) (2) (3)

where (1) indicates the error in estimating of Y at x_0 , (2) shows deviation of Y from true mean at x_0 and (3) indicates deviation of $\hat{Y}_{x_0}$ from true mean at x_0. From equation (4.19), the variance is:

$$VarY + Var\hat{Y}_{x_0} = \sigma^2 \sqrt{1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}} \tag{4.20}$$

Since the value of σ^2 is unknown, it is replaced by its estimated value, $S^2_{Y|x}$, in the equation (4.20).

4.2.3 Multiple Regression Analysis

4.2.3.1 Introduction

The principle of multiple regression is similar to that of single variable regression model, described in section 4.2.2. However, It is important to have the model under consideration inherently linear in the regression coefficients regardless of how the independent variables are defined. For example, $\mu_{Y/x} = \beta_0 e^{\beta_1 x}$ is inherently linear since it can be transformed into the equation of the form $\mu^*{}_{Y/x} = \beta_0^* + \beta_1 x$ which is linear in β_0^* and β_1 . On the other hand, an equation of the form $\mu_{Y/x_1,x_2} = e^{\beta_1 x_1} - e^{\beta_2 x_2}$ is nonlinear and can not be directly transformed into a linear equation in parameters β_1 and β_2 requiring special methods of nonlinear regression mostly done using available statistical software. In this research, the main focus is on linear regression model. More detailed information concerning nonlinear regression is given in references [3, 55, 57, 68].

4.2.3.2 Multiple linear regression model

The general form of a linear multiple regression with k independent variables is:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k + E \tag{4.21}$$

where β_0 , β_1 , β_2 , ... , β_k are the regression parameters to be estimated. It is also possible to have the independent variables x_1, x_2, ..., x_k expressed as function of some

other variables. In this case, some of the terms in equation (4.21) might appear in polynomial form. The assumptions applied to multiple linear regression model are similar to those for single variable linear regression model described in section 4.2.2. These assumptions include:

1. Independence: The values of dependent variable (Y) are statistically independent of each other.
2. Normality: The independent variable (Y) is normally distributed for fixed values of dependent variables ($x_1, x_2, \ldots, x_k$), hence,

$$Y \sim N\ (\mu_{Y/x_1,x_2,\ldots,x_k}, \sigma^2) \quad \text{or} \quad E \sim N(0, \sigma^2) \tag{4.22}$$

3. Linearity: The mean of dependent variable ($\mu_{Y/x_1,x_2,\ldots,x_k}$) is a linear function of combination of independent values of $x_1, x_2, \ldots, x_k$. Therefore,

$$\mu_{Y/x_1,x_2,\ldots,x_k} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k \tag{4.23}$$

or

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + E \tag{4.24}$$

where

$$E = Y - \mu_{Y/x_1,x_2,\ldots,x_k} \tag{4.25}$$

4. Homoscedasticity: The variance of Y is the same for any fixed combination of independent variables $x_1, x_2, \ldots, x_k$. That is,

$$\sigma^2_{Y/x_1,x_2,\ldots,x_k} = Var(Y_{/x_1,x_2,\ldots,x_k}) \equiv \sigma^2 \tag{4.26}$$

or

$$\sigma^2_{E/x_1,x_2,\ldots,x_k} \equiv \sigma^2$$

The independent variable (Y) and error (E) are random variables while independent variables $x_1, x_2, \ldots, x_k$ are fixed (nonrandom) quantities. Population parameters ($\beta_0, \beta_1, \beta_2, \ldots, \beta_k$) are unknown quantities which must be estimated using following procedures [7, 39, 55, 57, 84].

$$\hat{E}_i = Y_i - \hat{Y}_i = Y_i - (\hat{\beta}_0 + \hat{\beta}_1 x_{1i} + \hat{\beta}_2 x_{2i} + \ldots + \hat{\beta}_{ki}) \text{ , } i = 1,2,\ldots,n \tag{4.27}$$

where $\hat{E}_i$ is called residual. It is possible to conduct statistical inferences involving t and F distributions provided E_i has a Gaussian distribution [10, 39, 57, 71].

4.2.3.3 Determination of the best estimate of the multiple regression equation

The method of least square is used (section 4.2.2) in order to find the best fitted straight line. The method of maximum likelihood is used to determine the estimate values of the parameters in multiple regression model. The least square method and the method of maximum likelihood, explained later on, produce identical estimate of parameters if the assumption of Gaussian distribution holds.

4.2.3.4 The least- square method

The least square method is the one that chooses the best-fitting model of which the sum of squares of the distances between observed values and predicted ones is minimized. The smaller the deviations of predicted values from corresponding observed values the better the fit is. Thus,

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 x_1 + \hat{\beta}_2 x_2 + \ldots + \hat{\beta}_k x_k \tag{4.28}$$

represents the predicted values of response (Y) based on the estimated values of parameters β_0 , β_1 , β_2 , ..., β_k . Therefore, sum of squares of deviation of observed values of Y from corresponding predicted values (equation (4.28)) is given by

$$\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2=\sum_{i=1}^{n}(Y_i-\hat{\beta}_0-\hat{\beta}_1x_{1i}-...-\hat{\beta}_kx_{ki})^2 \tag{4.29}$$

where the minimum sum of squares is called the residual sum of squares denoted by SSE.

Computations involved estimation of parameters manually are tedious and time consuming. Thus, to obtain estimated values of parameters $\beta_0, \beta_1, \beta_2, ..., \beta_k$, one should employ any of several readily available statistical software (i.e. SAS). Some important properties of the least square solutions are given as follow:

a. The estimated values of $\beta_0, \beta_1, \beta_2, ..., \beta_k$ $(\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2, ..., \hat{\beta}_k)$ are normally distributed since it was assumed that Y-values are statistically independent of each other and normally distributed.

b. The multiple correlation coefficient between Y and $\hat{Y}$, $r_{Y,\hat{Y}}$, has the maximum value. That is,

$$r_{Y,\hat{Y}}=\frac{\sum_{i=1}^{n}(Y_i-\bar{Y})(\hat{Y}_i-\bar{\hat{Y}})}{\sqrt{\sum_{i=1}^{n}(Y_i-\bar{Y})^2\sum_{i=1}^{n}(\hat{Y}_i-\bar{\hat{Y}})^2}} \tag{4.30}$$

where $\hat{Y}_i$ is the predicted value of Y for the ith individual and $\bar{\hat{Y}}$ is the mean of the $\hat{Y}_i$'s. In addition, it is always true that $\bar{Y}=\bar{\hat{Y}}$; that is, the mean of the observed values is equal to the mean of the predicted values.

c. $$\sum_{i=1}^{n}(Y_i-\bar{Y})^2=\sum_{i=1}^{n}(\hat{Y}_i-\bar{Y})^2+\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2$$

where $SSY = \sum_{i=1}^{n} (Y_i - \overline{Y})^2$ is called the total sum of squares representing the total variability in the response value (Y) and $SSY = \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2$ is called residual sum of squares (sum of squares due to error) representing the amount of variation in response Y after using the independent variables $x_1, x_2, \ldots, x_k$ in the regression model to predict response Y.

Finally, $SSY - SSE = \sum_{i=1}^{n} (\hat{Y}_i - \overline{Y})^2$, is called the regression sum of squares, a measure of the amount of variation in the response value due to (or caused by) the model. More over, a quantitative measure of goodness of the fitted model using independent variables $x_1, x_2, \ldots, x_k$ is called R^2 and is recorded in ANOVA Table [55, 57, 68, 84]. The mathematical formula for R^2 is given by

$$R^2 = \frac{SSY - SSE}{SSY}, \qquad 0 < R^2 < 1 \tag{4.31}$$

Although the value of R^2 is increased by adding more relevant independent variables to the model, a small change in the value of R^2 may not be of any statistical significance.

4.2.3.5 Testing hypothesis in multiple regression

The testing procedures for multiple regression are similar to those of single variable regression with some of its own modifications. The overall regression test and partial F test are the common tests usually done on multiple regression. The former test indicates the model with k independent variables and response Y under null hypothesis as $H_0 : \beta_1 = \beta_2 = \ldots, \beta_k = 0$ at a prescribed significant level of α (i.e. 5%). If test is not significant we can not conclude that any of the $\beta_i^{'}s$ is different from zero. If in reality

$\beta_1 = \beta_2 =..., \beta_k = 0$ the model reduces to $Y = \beta_0 + \varepsilon$. This means that Y is not dependent on the independent variables $x_1, x_2, ..., x_k$. Moreover, the test statistic is:

$$F = \frac{MS_{regression}}{MS_{residual}} = \frac{(SSY - SSE)/k}{SSE/(n-k-1)} \tag{4.32}$$

where SSY and SSE are as described earlier. The computed value of F, equation (4.32), is checked against critical value of F, $F_{k,n-k-1,1-\alpha}$. If $F > F_{Critical}$ then H_0 is rejected meaning that at least one of the parameters β_1 , β_2 ,..., β_k , is different from zero. If the value of R^2 is known (i.e. ANOVA Table), one may compute F value given by

$$F = \frac{R^2/k}{(1-R^2)/(n-k-1)} \tag{4.33}$$

In fact equation (4.32) is the ratio of the two independent estimates of the true variance (σ^2) if the null hypothesis $H_0 : \beta_1 = \beta_2 =...= \beta_k = 0$ is true.

In addition, partial F test is conducted on each individual added independent variable in order to determine its significance in the overall model predicting the value of Y. This test results in obtaining additional information as a result of added variable(s) to the model whether to include it in the model or not. These procedures are done by computer using statistical analysis programs such as SAS. A brief discussion of the significance of F test is given below. For a complete account of formulas and procedures concerning partial F test, one may consult references [9, 39, 55, 57, 68].

Let x^* be an additional independent variable which is added to the model. We want to perform a test in order to determine the significant of the added variable to the model.

Therefore, it is required to compute all the sum of squares after adding x^{*} and perform a partial F test. Thus,

$$SS(x^{*} \mid x_1, x_2, \ldots, x_p) = \operatorname{Re} gSS(x_1, x_2, \ldots, x_p, x^{*}) - \operatorname{Re} gSS(x_1, x_2, \ldots, x_p) \tag{4.34}$$

$$F(x^{*} \mid x_1, x_2, \ldots, x_p) = SS(x^{*} \mid x_1, x_2, \ldots, x_p) / MS_{\text{Residual}}(x_1, x_2, \ldots, x_p, x^{*}) \tag{4.35}$$

If $F > F_{1,n-p-2,1-\alpha}$ then reject H_0 and conclude that addition of x^{*} to a model already containing $x_{1,} x_2, \ldots, x_p$ does significantly improve the prediction of response Y at a given significant level of α.

Although it is possible to extend the idea of partial F tests to multiple partial F test, it is beyond the scope of this research work to do so since variables are pre-selected and no additional variable is available to include in the model. However, the value of the multiple correlation coefficient $R_{Y/x_1, x_2, \ldots, x_k}$ (4.30) and $R^2_{Y/x_1, x_2, \ldots, x_k}$ is given by

$$R^2_{Y/x_1, x_2, \ldots, x_k} = \frac{SSY - SSE}{SSY} = \frac{\sum_{i=1}^{n} (Y_i - \bar{Y})^2 - \sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n} (Y_i - \bar{Y})^2} \tag{4.36}$$

The value of R^2 obtained from equation (4.36) is used to assess collinearity and the goodness of the fit of the regression model [3, 9, 55, 57].

4.2.3.6 Interaction and collinearity in regression model

Equation (4.21) gives one possible mathematical formulation for regression model which does not include any interaction (if any) or / and the higher power of independent variables. Apparently, the model will be inappropriate and inadequate if the significant interaction exist among the variables and not included in the model. Therefore, the first

step is to identify any significant interaction which might exist among the independent variables. An example of a regression model with interaction terms is given by

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_1 x_2 + \beta_6 x_2 x_3 + \beta_7 x_1 x_2 x_3 + E \qquad (4.37)$$

which has 1st order and 2nd order terms. It is also possible to have a model which has terms with higher degree than one. An example of such a model is:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_1 x_2^2 + \beta_6 x_2 x_3^2 + \beta_7 x_1 x_2 x_3 + E \qquad (4.38)$$

The more interaction terms are included in the model, the more difficulty in computational procedures and interpretation of the physical meaning of the model.

However, there is a limitation in the total number of such terms added to the model. With total number of n observations, a model with intercept β_0 can not have more than $(n-1)$ independent parameters.

Depending on the particular application, one may concentrate on the order of significance of the variables and their interactions. For example,

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_1 x_2 + \beta_6 x_1 x_3 + \beta_7 x_1 x_4 + E \qquad (4.39)$$

shows relationship between Y and variables x_1, x_2, x_3, x_4, where interaction between x_1 and other variables (x_2, x_3, x_4) is of significance to the given model. Another important check point concerning linear regression fit is collinearity. By definition, collinearity refers to having an independent variable to be an exact linear combination(s) of the other independent variable(s). For example, there are four independent variables x_1, x_2, x_3, x_4. In order to check for any collinearity among the independent variables, one must conduct

testing and find $R^2(x_1|x_2,x_3,x_4)$, $R^2(x_2|x_1,x_3,x_4)$, $R^2(x_3|x_1,x_2,x_4)$, and $R^2(x_4|x_1,x_2,x_3)$. If any of these multiple R^2-values equal 1.0, then there is collinearity.

This means that one independent variable is an exact combinations of the other three independent variables. Since the best fit model must have a unique estimate of parameters, any collinearity among the independent variables must be identified otherwise the model fails to have a unique estimates of parameters [9, 39, 55, 57].

4.2.4 Poisson Regression Analysis

4.2.4.1 Introduction

Poisson regression is a special case of regression in which the discrete data under consideration have a Poisson distribution. The technique of Poisson regression has been used extensively in applications mostly concerned with the rate ratio, count data, vehicle accident rate, and probability of an outcome given a fixed combinations values of independent variables involved. Due to the nature of our existing problem (pole accidents), it is appropriate (literature review) to use Poisson distribution probability function in order to establish an adequate statistical model which provide us with expected probability of pole hits for a given set of input variables. Therefore, Poisson regression technique and maximum likelihood principle are employed here in order to formulate the utility pole accident problem mathematically and establish a statistical model for vehicle utility pole accidents rate.

4.2.4.2 Poisson probability distribution

The Poisson probability distribution is given by

$$\Pr(Y;\mu) = \frac{\mu^{Y} e^{-\mu}}{Y!} \quad , \quad Y = 0, 1, \dots, \infty \tag{4.40}$$

where Y is a Poisson random variable which takes zero or positive integer value. According to equation (4.40), once the value of Y is given, the probability function ($\Pr(Y;\mu)$) is only a function of parameter μ which must be determined depending on the particular application. One of the important properties of Poisson distribution is that $Var(Y) = E(Y) = \mu$. More detailed information concerning Poisson distribution and Poisson regression can be found in references [3, 7, 9, 10, 71, 84].

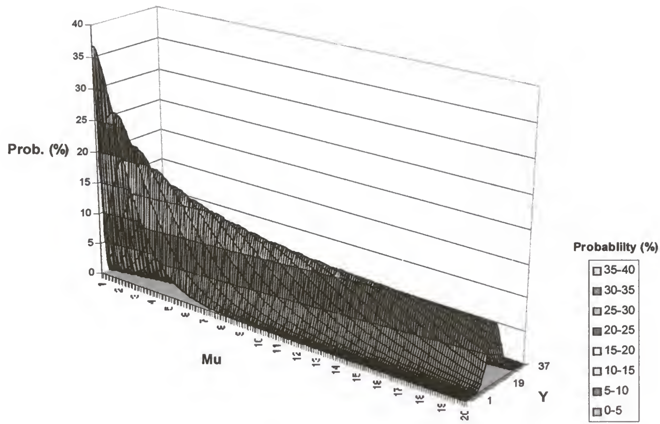


Figure 4.1: Poisson probability distribution function

4.2.4.3 Poisson regression

Poisson regression and multiple regression analysis are the same conceptually except for the way the distribution of data is defined. The former assumes the given data has Poisson distribution while the latter assigns the normal distribution to the given data set. Let the response $Y_i (i = 1,2,3,...,n)$ represents the total number of observed accidents (failures) during a given period of time and $X_i(x_{i1}, x_{i2},...,x_{ik})$ represent the set of k independent variables for $i = 1,2,...,n$ subgroups. Let $\beta = (\beta_0, \beta_1,...,\beta_k)$ be set of unknown parameters to be estimated and let $\lambda(X_i, \beta)$ denotes a function of β and X_i, which represents the rate of accident (failure). Let l_i represents the length of time in which accidents (failure) happened. Thus, the expected number of accidents in the ith subgroup is given by

$$E(Y_i) = \mu_i = l_i \lambda(X_i, \beta) \qquad , i = 1,2,..., n \tag{4.41}$$

assuming Y_i is a Poisson random variable and $\lambda(X_i, \beta) > 0$. Since it was assumed Y_i has a Poisson distribution, the Poisson probability distribution function takes the following form:

$$\Pr(Y_i, \mu_i) = \frac{\mu_i^{Y_i} e^{-\mu_i}}{Y_i!} \qquad , i = 1,2,...,n \tag{4.42}$$

Substitution of $\mu_i = l_i \lambda(X_i, \beta)$ into (4.42) gives

$$\Pr(Y_i, \beta) = \frac{[l_i \lambda(X_i, \beta)]^{Y_i} e^{-l_i \lambda(X_i, \beta)}}{Y_i!} \tag{4.43}$$

where $Y_i = 0,1,2,...,\infty$ and $i = 1,2,...,n$

The likelihood function for Poisson regression analysis is of the general form

$$L(Y,\beta) = \prod_{i=1}^{n} \Pr(Y_i,\beta) = \prod_{i=1}^{n} \{\frac{[l_i\lambda(X_i,\beta)]^{Y_i} e^{-l_i\lambda(X_i,\beta)}}{Y_i!}\} = \frac{\{\prod_{i=1}^{n}[l_i\lambda(X_i,\beta)]^{Y_i}\}\exp[-\sum_{i=1}^{n} l_i\lambda(X_i,\beta)]}{\prod_{i=1}^{n} Y_i!} \qquad (4.44)$$

where $E(Y_i) = \mu_i = l_i\lambda(X_i,\beta)$, $i = 1,2,\ldots,n$, defined earlier in equation (4.41). Equation (4.44) is very general in nature and it is required to choose an appropriate rate function $\lambda(X_i,\beta)$ which best describe the problem under study for modeling purposes. It is recommended to take $\lambda(X_i,\beta)$ in the form of $e^{\lambda_i^*}$ when $\lambda_i^* = \beta_0 + \sum_{i=1}^{n}\beta_j x_{ij}$, λ_i^* when $\lambda_i^* > 0$, and $Ln\lambda_i^*$ when $\lambda_i^* > 1$ [3, 40, 58]. Therefore, to obtain the maximum likelihood estimates of parameters $\beta_0,\beta_1,\ldots,\beta_k$ ($\hat{\beta}_0,\hat{\beta}_1,\ldots,\hat{\beta}_k$), one must solve k+1 equations simultaneously. These equations were obtained from partial differentiation of the log of $L(Y;\beta)$ in equation (4.44) with respect to β_j given by

$$\frac{\partial}{\partial\beta_j}[LnL(Y;\beta)] = 0 \qquad , j = 0,1,\ldots,k \qquad (4.45)$$

As it was mentioned earlier, Poisson distribution has the property: $E(Y_i) = Var(Y_i) = \mu_i = l_i\lambda(X_i,\beta)$ meaning variance of Y changes as a function of l_i, X_i, and β , thus, demanding following an iterative re-weighted least squares procedure. This is called Iterative re-weighted least squares (IRLS) and is performed using statistical software program (i.e. SAS).

4.3 Development of Utility Pole Accident Rate Predictive Model

In order to apply the technique of Poisson regression to the problem of traffic accidents (pole hits), it is necessary to identify the response variable and its corresponding

independent variables. Let ACC_R denotes the rate of accidents (response variable) and let posted speed (SPD), pole offset (POS), annual average daily traffic (ADT), and pole density (PDN) denote the independent variables to be used in the utility pole accident model. A general form of regression model describing the rate of accidents in terms of independent variables (SPD , POS , ADT , & PDN) is as follow:

$$\begin{aligned} Ln(ACC_R) = {} & \beta_0 + \beta_1(SPD) + \beta_2(POS) + \beta_3(ADT) + \beta_4(PDN) + \\ & \beta_5(SPD)(POS) + \beta_6(SPD)(ADT) + \beta_7(SPD)(PDN) + \\ & \beta_8(POS)(ADT) + \beta_9(POS)(PDN) + \beta_{10}(ADT)(PDN) + \\ & \beta_{11}(SPD)(POS)(ADT) + \beta_{12}(POS)(ADT)(PDN) + \beta_{13}(ADT)(PDN)(SPD) + \\ & \beta_{14}(PDN)(SPD)(POS) + \beta_{15}(SPD)(POS)(ADT)(PDN) + E \end{aligned} \tag{4.46}$$

However, in order to obtain a simpler model from equation (4.46), it is necessary to conduct some statistical tests concerning any interaction or/and collinearity which might exist among the independent variables. In case that there is no interactions at all (as it was the case in the previous studies), the general model (4.46) reduces to a much simpler and manageable form as:

$$Ln(ACC_R) = \beta_0 + \beta_1(SPD) + \beta_2(POS) + \beta_3(ADT) + \beta_4(PDN) + E \tag{4.47}$$

Since sensitivity analysis indicates that rate of accidents is almost directly proportional to ADT , PDN , and SPD while inversely proportional to POS , it is also possible to construct a non linear model of the form:

$$ACC_R = \frac{\beta_0 + \beta_1(SPD) + \beta_2(ADT) + \beta_3(PDN)}{\beta_4(POS)^{\alpha}} + E \tag{4.48}$$

In any case, it is very crucial to obtain a good fitted model regardless of the arrangement of the independent variables. To do so, it is required to employ statistical inferences about the estimated parameters and re-evaluate the adequacy of the model. The details and procedures concerning the data collection, data analysis, and determination of estimators for the proposed model are given in the following sections.

4.3.1 Data Analysis and Estimation of Parameters

The accident data file (1991-1996) obtained from department of transportation (DOT) contains a lot of information of which only three items, namely, total number of accidents, average annual daily traffic, and posted speed limit, were found useful in this analysis. The other two most important elements, namely, pole offset, and pole density, were obtained manually by measurement and video tape observation of the segments of roadways in which pole accidents occurred. Three counties (Marion, Alachua, and Broward) were selected for the purpose of analysis and modeling. Even though it was desirable to analyze more counties data, the resources for measuring pole offset and counting the pole density were either limited or unavailable.

4.3.2 Utility Pole Variables

Average pole offset. The mean of lateral pole offset in feet (0.3m) is calculated as:

$$\overline{X} = \sum_{i=1}^{n} x_i / N$$

where:

$\overline{X}$ = mean lateral pole offset

N = the number of poles on the selected section

x_i = the lateral pole offset for pole i

Standard deviation. The measure of spread of poles about the mean lateral pole offset which is calculated as follows:

$$\sigma = \sqrt{\sum_{i=1}^{n} (x_i - \overline{X})^2 / N}$$

where:

σ = standard deviation of pole offset

Pole density. The total number of utility poles within 40 feet (12 m) from the edge of pavement divided by segment length expressed as number of poles per mile (number of poles per 1.6 km).

Accident variables. Utility pole accidents are expressed either in accident frequency term or accident rate term. The description of each is given as follows:

Utility pole accident frequency (Acc/Mi/Yr). The total number of utility pole accidents per mile per year. The accident frequency is given as follows:

Acc/Mi/Yr = Acc / (L*T)

where:

Acc/mi/Yr = Utility pole accidents per mile per year

Acc= Total utility pole accidents occuring on the segment during the analysis period.

T = The analysis time period in years

L = The segment length in miles

Utility pole accident rate (Acc/HMVM). The total number of utility pole accidents per hundred million vehicle miles. The rate of utility pole accidents can be computed from the following equation:

Acc/HMVM = Acc* (100,000,000) / (365*ADT*L*T)

where:

Acc/HMVM = Utility pole accidents per 100 million vehicle miles

Acc = Total utility pole accidents on the segment during the analysis period

ADT = The average annual daily traffic on the segment during the analysis period

T = The analysis time period in years

L = The segment length in miles

Utility pole accident rate (Acc/HMVM). Utility pole accidents per billion vehicle-pole interactions. This is defined as the total number of utility pole accidents expressed as a function of the number of clear (unobstructed) poles times the ADT. This is given as follow: Acc/BVPI = Acc* (1,000,000,000) / (365* N*T* ADT) where Acc/BVPI = Utility pole accidents per billion vehicle-pole interactions.

A Poisson regression model was fitted to the data set using the procedure GENMOD from SAS software [67]. This procedure requires to introduce an appropriate link function in order to fit the model. Link function is an equation which relates mean response to the independent variables in the form of a linear model (linear predictor).

Depending on the distribution of the response values, the link function can have a variety of forms including the logarithmic form [39]. Since the response variable in this study is of the Poisson type, the link function $\ln \mu = \beta_0 + \sum \beta_j x_j$ was used and maximum likelihood estimators were computed using equation(4.45). One of the major purposes of using Poisson regression was to determine the rank and impact of each parameter on the utility pole accidents. The full model is given as follow (Table 4.2):

$$\hat{\mu} = e^{(\hat{\beta}_0 + \hat{\beta}_1(POS) + \hat{\beta}_2(PDN) + \hat{\beta}_3(ADT) + \hat{\beta}_4(SPD) + \hat{\beta}_5(SPD*PDN))} \quad (4.49)$$

In addition, it will be relatively easy to fit the model to the other counties data with few modifications to the existing model. Trend analysis , graph of number of accidents versus number of years, for all counties in State of Florida is included in Appendix D. Based on these graphs, there is no obvious indication of common pattern (s) among all counties pole accidents for the period of five years (1991-1996).

4.3.3 Correlation Analysis

Correlation analysis was done on the variables in order to identify the existence of any relationships between independent variables, thus, to avoid the problem of co-linearity and also to examine the strength of linear relationships between dependent variable and independent variables.

The dependent variable used in this analysis is:

- Utility pole accident rate, Acc/mi/yr (Acc/km/yr)

The independent variables are:

- Pole offset (POS)
- Pole density (PDN)
- Posted speed (SPD)
- Traffic volume (ADT)

The results of correlation analysis for all variables are given in Table 4.1. The value of correlation coefficient (r) is a measure of the strength of the linear relationship between the two variables. The higher the value of r, the closer linear relationships between two variables. According to Table 4.1, the correlation between accident rate

(dependent variable) and independent variables, pole offset and pole density, are much higher than those for ADT and posted speed.

Moreover, these results were also consistent with previous findings and research outlined in the literature review. The correlation between independent variables are:

- Pole density and pole offset (r = -0.23873)
- Pole offset and traffic volume (r = 0.19190)
- Pole density and traffic volume (r = 0.05900)
- Posted speed and traffic volume (r = 0.31404)
- Posted speed and pole offset (r = -0.04112)
- Posted speed and pole density (r = 0.29404)

These correlation values are not high enough to constitute strong linear relationships between independent variables. Another important test was conducted to check for any interaction among the independent variables using SAS program.

The estimated parameters, deviance, and all possible models obtained from procedure GENMOD [67] using SAS program are recorded in Table 4.2. The selection of the final model was based on the analysis of deviance where the model started initially with intercept and other independent variables were added to the model successively (see Table 4.2). The model with the least value of deviance was selected as the final full model given as follow:

$$\hat{\mu} = e^{(-9.5229-0.0834(POS)+0.2011(PDN)+0.00001(ADT)+0.2326(SPD)-0.0043(SPD*PDN))} \tag{4.50}$$

Table 4.1: Pearson correlation coefficients for all variables.

VARIABLES	ACC_R	POS	PDN	ADT	PSD
ACC_R	1.00000	-0.43082	0.48227	0.12749	0.02048
POS	-0.43082	1.00000	-0.23873	0.19190	-0.04112
PDN	0.48227	-0.23873	1.00000	0.05900	0.29404
ADT	0.12749	0.19190	0.05900	1.00000	0.31404
PSD	0.02048	-0.04112	0.29404	0.31404	1.00000

Table 4.2: Summary of statistics, estimated coefficients, deviance, and model.

VARIABLES	ST.ERROR	COEFFICIENTS	DEVIANCE	MODEL
	7.8578	β^{*}_{o}=-9.5229	252.28	β_o
POS	0.0419	β_1=-0.0834	186.52	$\beta_o + \beta_1(POS)$
PDN	0.1084	β_2=0.2011	153.05	$\beta_o + \beta_1(POS) + \beta_2(PDN)$
ADT	0.1236	β_3=0.00001	143.17	$\beta_o + \beta_1(POS) + \beta_2(PDN) + \beta_3(ADT)$
PSD	0.1794	β_4=0.2326	136.12	$\beta_o + \beta_1(POS) + \beta_2(PDN) + \beta_3(ADT) + \beta_4(PSD)$
PDN*PSD	0.0025	β_5=-0.0043	115.52	$\beta_o + \beta_1(POS) + \beta_2(PDN) + \beta_3(ADT) + \beta_4(PSD) + \beta_5(PDN*PSD)$

* Intercept

The estimated values of mean ($\hat{\mu}$) were computed for some selected values of input variables, recorded in Tables 4.3-4.5, using equation (4.50). Based on these values, rate of utility pole accident increases as ADT or/and pole density increases. Moreover, rate of accident decreases as pole offset or posted speed increases assuming ADT is kept constant. These findings are consistent with the previous studies. Finally, the values of utility pole accident rate, at ADT=30,000 and posted speed =40 (mph), were computed using equation (4.50). These values were substituted in equation (4.42) in order to generate the probability of utility pole accident rate, recorded in Table 4.6.

Table 4.3: Predicted utility pole accident rate for various values of pole offset and pole density at ADT=20,000 and posted speed=35 (mph).

	ADT LEVEL: 20000					POSTED SPEED (MPH) : 35					
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	0.71	0.92	1.18	1.53	1.96	2.53	3.26	4.20	5.40	6.96	8.96
5	0.56	0.72	0.92	1.19	1.53	1.97	2.54	3.27	4.21	5.42	6.98
7	**0.47**	**0.61**	**0.78**	**1.01**	**1.29**	**1.67**	**2.15**	**2.77**	**3.56**	**4.59**	**5.91**
10	**0.37**	**0.47**	**0.61**	**0.78**	**1.01**	**1.30**	**1.67**	**2.15**	**2.77**	**3.57**	**4.60**
12	**0.31**	**0.40**	**0.51**	**0.66**	**0.85**	**1.10**	**1.42**	**1.82**	**2.35**	**3.02**	**3.89**
15	**0.24**	**0.31**	**0.40**	**0.52**	**0.66**	**0.86**	**1.10**	**1.42**	**1.83**	**2.35**	**3.03**
20	0.16	0.20	0.26	0.34	0.44	0.56	0.73	0.94	1.20	1.55	2.00
25	0.10	0.14	0.17	0.22	0.29	0.37	0.48	0.62	0.79	1.02	1.32
30	0.07	0.09	0.11	0.15	0.19	0.24	0.32	0.41	0.52	0.67	0.87

Table 4.4: Predicted utility pole accident rate for various values of pole offset and pole density at ADT=30,000 and posted speed=35 (mph).

	ADT LEVEL: 30000					POSTED SPEED (MPH) : 35					
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	0.79	1.02	1.31	1.69	2.17	2.80	3.60	4.64	5.97	7.69	9.91
5	0.61	0.79	1.02	1.31	1.69	2.18	2.80	3.61	4.65	5.99	7.71
7	**0.52**	**0.67**	**0.86**	**1.11**	**1.43**	**1.84**	**2.37**	**3.06**	**3.94**	**5.07**	**6.53**
10	**0.40**	**0.52**	**0.67**	**0.87**	**1.11**	**1.43**	**1.85**	**2.38**	**3.07**	**3.95**	**5.08**
12	**0.34**	**0.44**	**0.57**	**0.73**	**0.94**	**1.21**	**1.56**	**2.01**	**2.59**	**3.34**	**4.30**
15	**0.27**	**0.34**	**0.44**	**0.57**	**0.73**	**0.95**	**1.22**	**1.57**	**2.02**	**2.60**	**3.35**
20	0.18	0.23	0.29	0.38	0.48	0.62	0.80	1.03	1.33	1.71	2.21
25	0.12	0.15	0.19	0.25	0.32	0.41	0.53	0.68	0.88	1.13	1.46
30	0.08	0.10	0.13	0.16	0.21	0.27	0.35	0.45	0.58	0.74	0.96

Table 4.5: Predicted utility pole accident rate for various values of pole offset and pole density at ADT=20,000 and posted speed=45 (mph).

	ADT LEVEL: 20000					POSTED SPEED (MPH) : 45					
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	3.09	3.21	3.34	3.47	3.60	3.74	3.89	4.04	4,19	4.35	4.52
5	2.41	2.50	2.60	2.70	2.80	2.91	3.03	3.14	3.26	3.39	3.52
7	**2.04**	**2.12**	**2.20**	**2.28**	**2.37**	**2.47**	**2.56**	**2.66**	**2.76**	**2.87**	**2.98**
10	**1.59**	**1.65**	**1.71**	**1.78**	**1.85**	**1.92**	**1.99**	**2.07**	**2.15**	**2.23**	**2.32**
12	**1.34**	**1.40**	**1.45**	**1.51**	**1.56**	**1.62**	**1.69**	**1.75**	**1.82**	**1.89**	**1.96**
15	**1.05**	**1.09**	**1.13**	**1.17**	**1.22**	**1.27**	**1.31**	**1.36**	**1.42**	**1.47**	**1.53**
20	0.69	0.72	0.74	0.77	0.80	0.83	0.87	0.90	0.93	0.97	1.01
25	0.45	0.47	0.49	0.51	0.53	0.55	0.57	0.59	0.62	0.64	0.66
30	0.30	0.31	0.32	0.34	0.35	0.36	0.38	0.39	0.41	0.42	0.44

Table 4.6: Probability of utility pole accident rate for various values of offset and pole density at ADT=30,000 , expected rate of accident=3 (acc/mile/year), and SPD=40 (mph).

ADT LEVEL: 30000 POSTED SPEED (MPH) : 40 # OF ACCIDENTS PER MILE PER YEAR= 3											
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	0.14	0.17	0.20	0.22	0.22	0.22	0.20	0.17	0.13	0.09	0.05
5	0.10	0.12	0.15	0.18	0.20	0.22	0.22	0.21	0.19	0.16	0.11
7	0.07	0.09	0.12	0.15	0.17	0.20	0.22	0.22	0.22	0.19	0.16
10	0.04	0.06	0.08	0.10	0.13	0.15	0.18	0.21	0.22	0.22	0.21
12	0.03	0.04	0.06	0.07	0.10	0.12	0.15	0.18	0.20	0.22	0.22
15	0.02	0.02	0.03	0.04	0.06	0.08	0.10	0.13	0.16	0.19	0.21
20	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.06	0.08	0.11	0.13

In addition, corresponding three dimensional graphs of the values recorded in these tables are plotted using SAS (goption) in order to visualize the relationships among these variables easily. Figures 4.2 through 4.4 illustrate rate of accident vs. pole offset and pole density at different values of ADT and posted speed. Figure 4.5 also illustrates the probability of utility pole accident rate vs. pole offset and pole density at posted speed = 40 (mph), ADT=30,000 and expected rate of accident=3 (acc/mile/year).

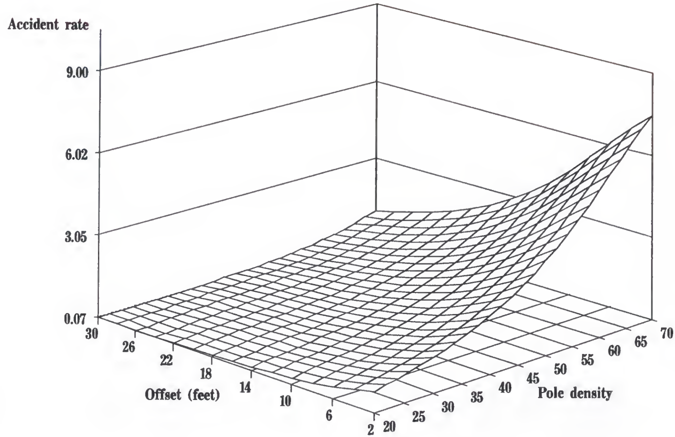


Figure 4.2: Utility pole accident rate vs. pole offset and pole density at ADT= 20,000 and SPD= 35 (mph).

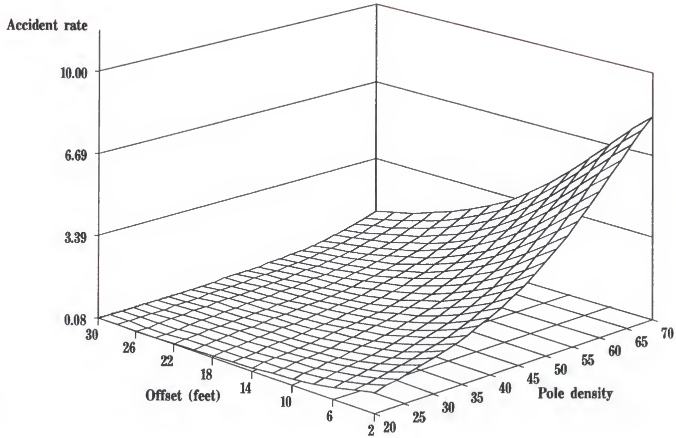


Figure 4.3: Utility pole accident rate vs. pole offset and pole density at ADT= 30,000 and SPD= 35 (mph).

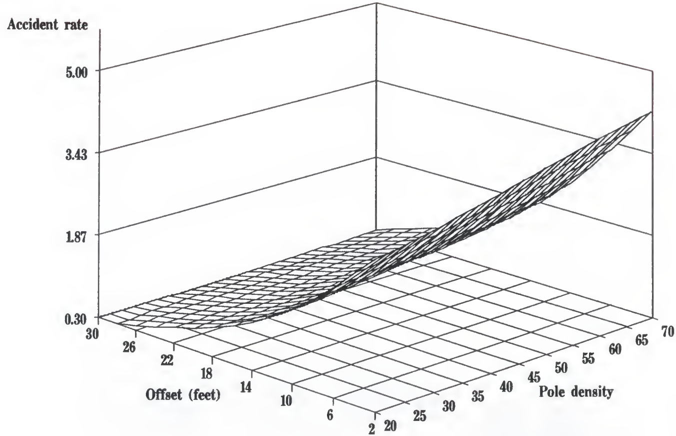


Figure 4.4: Utility pole accident rate vs. pole offset and pole density at ADT= 20,000 and SPD= 45 (mph).

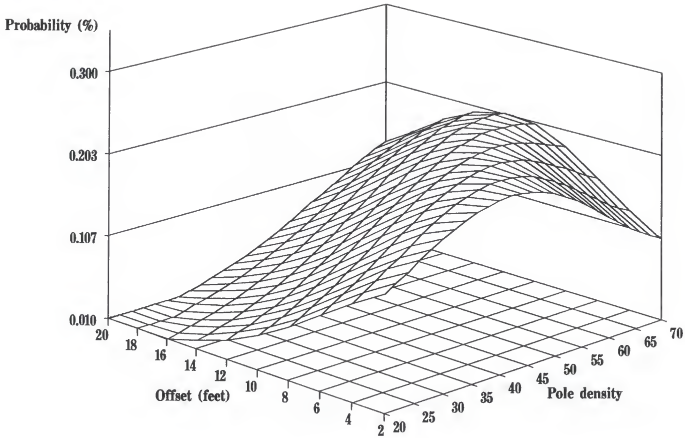


Figure 4.5: Probability of utility pole accident rate vs. pole offset and pole density at ADT= 30,000 SPD= 40 (mph), and expected rate of accident=3 (acc/mile/year).

CHAPTER 5
SENSITIVITY ANALYSIS

5.1 Introduction

The use of cost-effectiveness procedures requires a large number of input, as described in Chapter 4. Therefore, it is crucial to identify the factors which have the greatest influence on vehicle utility pole accident rate in order to obtain reasonable predicted values. The input variables are divided into two categories, namely, descriptive variables and quantitative variables. The former are not used directly in the analysis of accident but they are useful to the users in describing the site characteristics. However, the latter are used directly in the model which analyze the input data and provide the result in term of predicted rate of accident or probability of accident. Descriptive variables are listed below:

- Right of way width
- Road way width
- Number of lanes
- Pavement type (Concrete or asphalt)
- Road way alignment (Tangent, gentle curve, and/or sharp curve)
- Operation (One-way or two-way)
- Terrian (Flat, rolling, and/or hilly)

- Pole type (Wood, metal, or concrete)
- Shoulder width
- Location description (Road name, etc.)

Even though these description factors are found to have some effects on utility pole accident, they were found to be insignificant in the analysis of utility pole accidents [87, 88].

There are several variables, used in the cost-effectiveness procedures, which have significant effect on expected utility pole accident rate. The three most important quantitative parameters are pole offset, pole density, traffic volume. Pole configuration is also important in describing the geometry and alignment of the poles but it is not used in the predictive model. The conversion factor between pole spacing (ft/pole) and pole density (poles/mile) is given in Table 5.1 and the significance of each of these parameters is discussed in the following sections.

5.2 Utility Pole Offset

A summary of utility pole accident rate vs. combined effect of pole density and pole offset at fixed values of ADT is given in Table 5.2. From this table, it can be seen that for a fixed value of average daily traffic (ADT) and pole density one can find the variation in utility pole accident rate due to pole offset only. For example, at an ADT 20,000 and pole density of 40 poles/mile (25 poles/km), utility pole accident rate varies from 2.19/mile/year (1.36/km/year) for a 2 feet (0.6 m) offset to 0.40/mile/year (0.25/km/year) for an offset of 30 feet (9 m). This corresponds to a difference of 1.79 accidents/mile/year which accounts for almost 87.7% of the number of utility pole accidents for the range of offset between 2 to 15 feet.

Table 5.1: Conversion of pole spacing to poles per mile [87].

Pole Spacing (Feet/pole)	Pole Density (Poles/Miles)
50	106
60	88
70	75
80	66
90	59
100	53
110	48
120	44
130	41
140	38
150	35
175	30
200	26

- Remark: This table of conversion is only for one line of utility poles. For two lines of utility poles, one must do the conversion for each line separately and then add the result.

1 Foot = 0.333 m
1 pole/mile = 0.6215 poles/km

Table 5.2: Predicted utility pole accident rate for different values of annual average daily traffic (ADT), pole offset, and pole density [88].

	ADT LEVEL 1000 POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	0.49	0.61	0.72	0.84	0.96	1.08	1.19	1.31	1.43	1.54	1.66
5	0.27	0.33	0.4	0.47	0.54	0.6	0.67	0.74	0.81	0.87	0.94
7	0.21	0.26	0.32	0.37	0.43	0.48	0.54	0.6	0.65	0.71	0.76
10	0.16	0.21	0.25	0.29	0.34	0.38	0.43	0.47	0.52	0.56	0.61
12	0.14	0.18	0.22	0.26	0.3	0.34	0.38	0.42	0.46	0.5	0.54
15	0.12	0.15	0.19	0.22	0.26	0.29	0.33	0.36	0.4	0.43	0.47
20	0.09	0.12	0.15	0.18	0.21	0.24	0.27	0.3	0.33	0.36	0.39
25	0.08	0.1	0.13	0.15	0.18	0.2	0.23	0.25	0.28	0.31	0.33
30	0.06	0.09	0.11	0.13	0.16	0.18	0.2	0.22	0.25	0.27	0.29

	ADT LEVEL 2000 POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	0.56	0.67	0.79	0.91	1.02	1.14	1.26	1.37	1.49	1.61	1.72
5	0.3	0.37	0.44	0.51	0.57	0.64	0.71	0.78	0.84	0.91	0.98
7	0.24	0.29	0.35	0.41	0.46	0.52	0.57	0.63	0.68	0.74	0.79
10	0.19	0.23	0.27	0.32	0.36	0.41	0.45	0.5	0.54	0.59	0.63
12	0.16	0.2	0.24	0.28	0.32	0.36	0.4	0.44	0.48	0.52	0.56
15	0.14	0.17	0.21	0.24	0.28	0.31	0.35	0.38	0.42	0.45	0.49
20	0.11	0.14	0.17	0.2	0.23	0.25	0.28	0.31	0.34	0.37	0.4
25	0.09	0.12	0.14	0.17	0.19	0.22	0.24	0.27	0.29	0.32	0.35
30	0.08	0.1	0.12	0.14	0.17	0.19	0.21	0.24	0.26	0.28	0.31

Table 5.2: continued.

ADT LEVEL 3000	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	0.62	0.74	0.85	0.97	1.09	1.2	1.32	1.44	1.56	1.67	1.79
5	0.34	0.41	0.48	0.54	0.61	0.68	0.75	0.81	0.88	0.95	1.01
7	0.27	0.33	0.38	0.44	0.49	0.55	0.6	0.66	0.71	0.77	0.82
10	0.21	0.25	0.3	0.34	0.39	0.43	0.48	0.52	0.57	0.61	0.66
12	0.18	0.22	0.26	0.3	0.34	0.38	0.42	0.46	0.5	0.54	0.58
15	0.16	0.19	0.23	0.26	0.3	0.33	0.37	0.4	0.43	0.47	0.5
20	0.12	0.15	0.18	0.21	0.24	0.27	0.3	0.33	0.36	0.39	0.42
25	0.1	0.13	0.15	0.18	0.21	0.23	0.26	0.28	0.31	0.33	0.36
30	0.09	0.11	0.13	0.16	0.18	0.2	0.23	0.25	0.27	0.3	0.32

ADT LEVEL 4000	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	0.69	0.8	0.92	1.04	1.15	1.27	1.39	1.5	1.62	1.74	1.85
5	0.38	0.45	0.51	0.58	0.65	0.72	0.78	0.85	0.92	0.98	1.05
7	0.3	0.36	0.41	0.47	0.52	0.58	0.63	0.69	0.74	0.8	0.85
10	0.23	0.28	0.32	0.37	0.41	0.46	0.5	0.55	0.59	0.64	0.68
12	0.21	0.25	0.29	0.33	0.37	0.41	0.45	0.49	0.53	0.57	0.61
15	0.18	0.21	0.24	0.28	0.31	0.35	0.38	0.42	0.45	0.49	0.52
20	0.14	0.17	0.2	0.23	0.26	0.29	0.32	0.35	0.38	0.41	0.43
25	0.12	0.14	0.17	0.19	0.22	0.25	0.27	0.3	0.32	0.35	0.37
30	0.1	0.12	0.15	0.17	0.19	0.22	0.24	0.26	0.29	0.31	0.33

Table 5.2: continued.

ADT LEVEL 5000											
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	0.75	0.87	0.98	1.1	1.22	1.33	1.45	1.57	1.69	1.8	1.92
5	0.42	0.48	0.55	0.62	0.69	0.75	0.82	0.89	0.95	1.02	1.09
7	0.33	0.39	0.44	0.5	0.55	0.61	0.66	0.72	0.77	0.83	0.88
10	0.26	0.3	0.35	0.39	0.44	0.48	0.53	0.57	0.62	0.66	0.7
12	0.23	0.27	0.31	0.35	0.39	0.43	0.47	0.51	0.55	0.59	0.63
15	0.19	0.23	0.26	0.3	0.33	0.37	0.4	0.44	0.47	0.51	0.54
20	0.16	0.19	0.22	0.25	0.27	0.3	0.33	0.36	0.39	0.42	0.45
25	0.13	0.16	0.18	0.21	0.23	0.26	0.29	0.31	0.34	0.36	0.39
30	0.11	0.14	0.16	0.18	0.21	0.23	0.25	0.28	0.3	0.32	0.34

ADT LEVEL 10,000											
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	20	25	30	35	40	45	50	55	60	65	70
2	1.07	1.19	1.31	1.43	1.54	1.66	1.78	1.89	2.01	2.13	2.24
5	0.6	0.67	0.74	0.8	0.87	0.94	1.01	1.07	1.14	1.21	1.28
7	0.48	0.54	0.59	0.65	0.71	0.76	0.82	0.87	0.93	0.98	1.04
10	0.38	0.43	0.47	0.52	0.56	0.61	0.65	0.69	0.74	0.78	0.83
12	0.34	0.38	0.42	0.46	0.5	0.54	0.58	0.62	0.66	0.7	0.74
15	0.29	0.33	0.36	0.4	0.43	0.47	0.5	0.54	0.57	0.61	0.64
20	0.24	0.27	0.3	0.33	0.36	0.39	0.41	0.44	0.47	0.5	0.53
25	0.2	0.23	0.25	0.28	0.31	0.33	0.36	0.38	0.41	0.43	0.46
30	0.18	0.2	0.22	0.25	0.27	0.29	0.32	0.34	0.36	0.39	0.41

Table 5.2: continued.

ADT LEVEL 20,000											
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*	*65*	*70*
2	1.72	1.84	1.96	2.07	2.19	2.31	2.43	2.54	2.66	2.78	2.89
5	0.98	1.04	1.11	1.18	1.25	1.31	1.38	1.45	1.52	1.58	1.65
7	0.79	0.85	0.9	0.96	1.01	1.07	1.12	1.18	1.23	1.29	1.34
10	0.63	0.67	0.72	0.76	0.81	0.85	0.9	0.94	0.99	1.03	1.08
12	0.56	0.6	0.64	0.68	0.72	0.76	0.8	0.84	0.88	0.92	0.96
15	0.49	0.52	0.55	0.59	0.62	0.66	0.69	0.73	0.76	0.8	0.83
20	0.4	0.43	0.46	0.49	0.52	0.55	0.58	0.61	0.64	0.67	0.7
25	0.35	0.37	0.4	0.42	0.45	0.47	0.5	0.53	0.55	0.58	0.6
30	0.31	0.33	0.35	0.37	0.4	0.42	0.44	0.47	0.49	0.51	0.54

ADT LEVEL 30,000											
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*	*65*	*70*
2	2.37	2.49	2.61	2.72	2.84	2.96	3.07	3.19	3.31	3.43	3.54
5	1.35	1.42	1.49	1.55	1.62	1.69	1.76	1.82	1.89	1.96	2.03
7	1.1	1.15	1.21	1.26	1.32	1.37	1.43	1.48	1.54	1.59	1.65
10	0.88	0.92	0.97	1.01	1.06	1.1	1.14	1.19	1.23	1.28	1.32
12	0.78	0.82	0.86	0.9	0.94	0.98	1.02	1.06	1.1	1.14	1.18
15	0.68	0.71	0.75	0.78	0.82	0.85	0.89	0.92	0.96	0.99	1.03
20	0.56	0.59	0.62	0.65	0.68	0.71	0.74	0.77	0.8	0.83	0.86
25	0.49	0.51	0.54	0.57	0.59	0.62	0.64	0.67	0.69	0.72	0.75
30	0.43	0.46	0.48	0.5	0.53	0.55	0.57	0.59	0.62	0.64	0.66

Table: 5.2: continued.

ADT LEVEL 40,000											
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*	*65*	*70*
2	3.02	3.14	3.26	3.37	3.49	3.61	3.72	3.84	3.96	4.07	4.19
5	1.73	1.79	1.86	1.93	2	2.06	2.13	2.2	2.27	2.33	2.4
7	1.4	1.46	1.51	1.57	1.62	1.68	1.73	1.79	1.84	1.9	1.95
10	1.12	1.17	1.21	1.26	1.3	1.35	1.39	1.44	1.48	1.53	1.57
12	1	1.04	1.08	1.12	1.16	1.2	1.24	1.28	1.32	1.36	1.4
15	0.87	0.91	0.94	0.98	1.01	1.05	1.08	1.12	1.15	1.19	1.22
20	0.73	0.76	0.79	0.82	0.85	0.87	0.9	0.93	0.96	0.99	1.02
25	0.63	0.66	0.68	0.71	0.73	0.76	0.79	0.81	0.84	0.86	0.89
30	0.56	0.58	0.61	0.63	0.65	0.68	0.7	0.72	0.75	0.77	0.79

ADT LEVEL 50,000											
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*	*65*	*70*
2	3.67	3.79	3.9	4.02	4.14	4.26	4.37	4.49	4.61	4.72	4.84
5	2.1	2.17	2.24	2.3	2.37	2.44	2.51	2.57	2.64	2.71	2.78
7	1.71	1.76	1.82	1.87	1.93	1.98	2.04	2.09	2.15	2.21	2.26
10	1.37	1.42	1.46	1.51	1.55	1.59	1.64	1.68	1.73	1.77	1.82
12	1.23	1.27	1.3	1.34	1.38	1.42	1.46	1.5	1.54	1.58	1.62
15	1.07	1.1	1.14	1.17	1.21	1.24	1.28	1.31	1.35	1.38	1.42
20	0.89	0.92	0.95	0.98	1.01	1.04	1.07	1.1	1.13	1.15	1.18
25	0.77	0.8	0.83	0.85	0.88	0.9	0.93	0.95	0.98	1	1.03
30	0.69	0.71	0.74	0.76	0.78	0.8	0.83	0.85	0.87	0.9	0.92

Table 5.2: continued.

ADT LEVEL 60,000											
	POLE DENSITY (POLES/MILE)										
POLE OFFSET (FEET)	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*	*65*	*70*
2	4.32	4.44	4.55	4.67	4.79	4.9	5.02	5.14	5.26	5.37	5.49
5	2.48	2.54	2.61	2.68	2.75	2.81	2.88	2.95	3.01	3.08	3.15
7	2.02	2.07	2.13	2.18	2.24	2.29	2.35	2.4	2.46	2.51	2.57
10	1.62	1.66	1.71	1.75	1.8	1.84	1.89	1.93	1.97	2.02	2.06
12	1.45	1.49	1.53	1.57	1.61	1.65	1.69	1.73	1.77	1.81	1.85
15	1.26	1.3	1.33	1.36	1.4	1.43	1.47	1.5	1.54	1.57	1.61
20	1.05	1.08	1.11	1.14	1.17	1.2	1.23	1.26	1.29	1.32	1.35
25	0.92	0.94	0.97	0.99	1.02	1.04	1.07	1.1	1.12	1.15	1.17
30	0.82	0.84	0.86	0.89	0.91	0.93	0.96	0.98	1	1.02	1.05

As a result, it is concluded that offset has a large effect on utility pole accident rate, particularly for the offset of 2 to 15 feet (0.6 to 4.5 m). Utility pole accident rate increases slowly as average daily traffic increases. For example, at ADT of 40,000 and pole density of 40 poles/mile (25 poles/km), utility pole accident rate varies from 3.49/mile/year (2.17/km/year) at 2-feet (0.6m) offset to 0.65/mile/year (0.4 poles /km/year) at 30 feet (9m) offsets, a difference of 2.84 accidents /mile/year (1.77 accidents/km/year). Figures 5.1 and 5.2 illustrate the utility pole accident rate as a function of pole offset for different values of ADT and pole density [87].

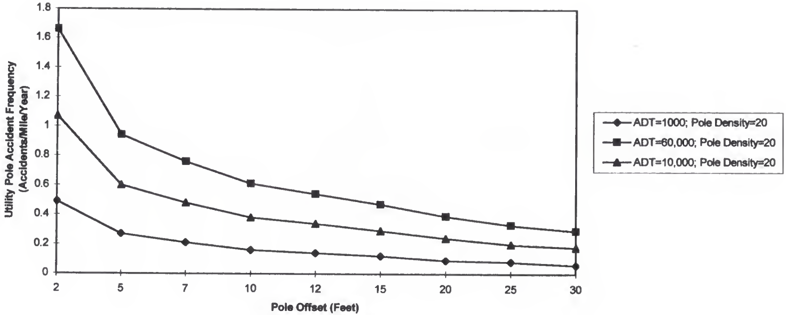


Figure 5.1: Utility pole accident frequency vs. pole offset for fixed values of ADT and pole density.

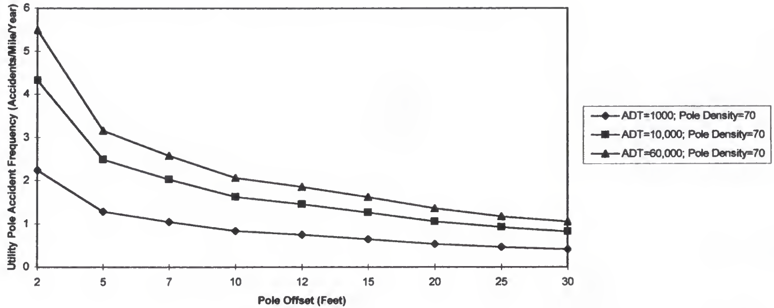


Figure 5.2: Utility pole accident frequency vs. pole offset for fixed values of ADT and pole density.

5.3 Pole Density

The effect of pole density on utility pole accident rate is illustrated in Figure 5.3. According to Figure5.3, utility pole accident rate increases as pole density increases. However, the effect of pole density on utility pole accident rate is not as strong as that of pole offset indicating almost a straight line relationship between pole density and accident rate.

From Table 5.2, it can be seen that, for example, for a daily traffic volume of 20,000 and pole offset of 2 feet (0.3m), utility pole accidents range from 1.72 accidents per mile per year for 20 poles per mile (13 poles/km) to 2.89 accidents per mile per year for 70 poles per mile (44 poles/km). An increase of 5 poles per mile (3 poles/km) results in a change of approximately 0.12 accidents per mile per year. For annual average daily traffic of 20,000 and 30 feet (9m) offset, utility pole accident rate range from 0.30 accidents per mile per year for 20 poles per mile (13poles/km) to 0.54 for 70 poles per mile (44 poles/km). In this case, an increase of approximately 0.02 accidents per mile per year occurs for every increase of 5 poles per mile (6 poles/km). This suggests that greater accident reduction may be obtained due to increasing pole offset than due to reducing pole density.

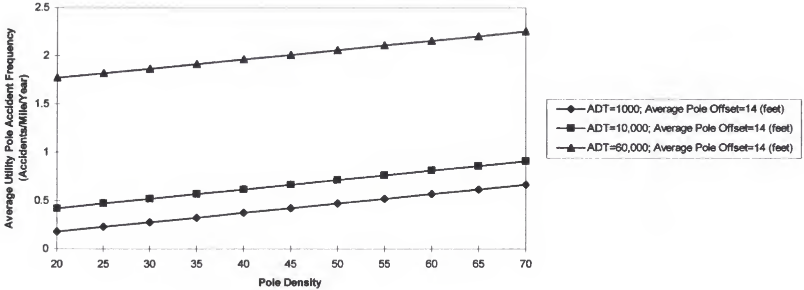


Figure 5.3: Utility pole accidents frequency vs. pole density at different values of ADT and fixed values of pole offset.

5.4 Annual Average Daily Traffic

The utility pole accident rates, Table 5.2, also provide the trend of the effect of annual average daily traffic (ADT) on utility pole accidents. By selecting a fixed values for pole density and pole offset, one can easily see the variations among the rate of utility pole accidents due to corresponding changes in values of ADT. For example, with pole density of 70 poles/mile (44 poles/km) and pole offset of 2 feet (0.6m), utility pole accident rate increases by approximately 0.06 per mile per year with an increment of 1,000 vehicles per day (i.e. 1.66 for 1,000 ADT, 1.72 for 2,000 ADT, 1.79 for 3,000ADT, 1.85 for 4,000 ADT, etc.).

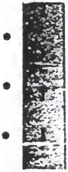
For 20 poles per mile (13poles/km) and 30 feet (9m) offset, there is an increase of almost 0.01 to 0.02 accidents per mile per year for each increment of 1,000 vehicles per day (i.e. 0.06 at 1,000 ADT, 0.08 at 2,000 ADT, 0.09 at 3,000 ADT, etc).

5.5 Utility Pole Configurations

Pole configuration indicates the allocation of utility poles with respect to the roadway. The most common pole configurations, shown in Figure 5.4, are:

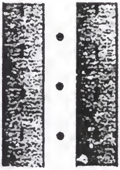
- Utility poles on one side of roadway
- Utility poles on both sides of roadway
- Utility poles in median only
- Utility poles on one side and median
- Utility poles on both sides and median

The analysis and cost-effective procedures outlined in this research applies only to the

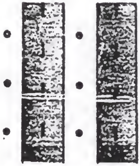


Utility pole placement of one side.

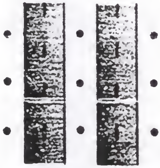
Utility pole placement of both sides.



Utility pole placementin median.



Utility pole placement
on one side and in median.



Utility pole placement
on both sides and in median.

Figure 5.4: Utility pole configurations.

first two cases, namely, utility pole on one or both sides of the roadway. The other three cases were not investigated due to the lack of sufficient samples of these types of sections involved in utility pole accidents.

In summary, it was established that pole offset, pole density, and average daily traffic (ADT) take the ranks of first ,second, and third, respectively, with respect to their significance and contribution to the utility pole accidents. The effect of design speed or vehicle travel speed is examined in chapter 4 where the predictive model is developed and tested.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The collected FDOT and field data were sorted, organized, and analyzed in order to identify the crucial factors contributing to the utility pole accidents in rural area and to establish any possible statistical relationship which might exists among these parameters.

The ultimate goal was to produce a utility pole accident rate predictive model by formulating number of accidents vs. available identified factors such as pole offset, pole density, ADT, and posted or travel speed.

As a result, statistical utility pole accident rate predictive model was established using procedure GENMOD from SAS software. The testing procedures revealed that pole offset and pole density are the most important independent variables to be considered in the predictive model. On the other hand, the contribution of ADT on utility pole accidents was almost insignificant, a surprise to the previous studies.

However, inclusion of travel speed or posted speed has something to do with insignificant of ADT in the model since posted speed and ADT are both a function of time, hence, they are not independent of each other. Previous studies did not include speed as a parameter in the predictive model.

The testing procedures also uncovered an important fact that influence of posted speed on utility pole accidents rate was insignificant. Moreover, interaction between pole

density and posted speed was found to be significant and incorporated in the model as the only interaction term. Replacing the posted speed with the travel speed of vehicle (if known) enhances the predictive model further since majority of vehicle-utility pole accidents are due to higher speed than the posted speed and other related human errors.

The developed model reasonably predicts the probability of utility pole accident rate using Poisson probability function and provides important information and insight into prioritization and project ranking, thus, enhancing the Benefit-Cost ratio analysis. It is also important to understand that no statistical model remains valid indefinitely but requires evaluation, modification, and validation occasionally.

In summary, it is expected that the developed model will equip FDOT, transportation agencies, and utility companies with an adequate and powerful tool to prioritize utility pole projects and to allocate the corresponding funds appropriately. This is a crucial process since the bottom line of all these activities and research is economy, decision making, and optimization.

6.2 Recommendations for Future Research

As you might have already noticed, several other important factors were not included in this study either data were not available, complete, or reliable. However, qualitative factors such as visibility, weather condition, driving habits, etc. also play an important role in vehicle-utility pole accidents. Thus, there is a lot of space for further exploration of the model by combining the concept of categorical data analysis and regression analysis in order to incorporate as many effective variables as possible in the predictive model.

Moreover, one may also look into the roadway design criteria and search for any possible factor which might have contributed to utility pole hits. Elements of roadway geometry such as elevation, curvature, and surface condition should be given special consideration in the study of pole accidents. This in turn requires a careful measurements and record keeping of the above mentioned elements. The ingredients for such a intense research and development will continue to be high degree of determination, stamina, patience, and careful data collection skills.

APPENDIX A

FIELD DATA COLLECTION FORMS

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM A: SITE DESCRIPTION

Road Name or Route Identification:____________________________
Beginning Milepost:__________ Ending:__________ Length:___________ (miles)
Area Type (Urban or Rural)_________________ Curb (Year or No)___________
Right of-Way width:_______________ Shoulder Width:______________ Feet
Current Daily Traffic volume (ADT_c):_____ Posted Speed Limit:_______ mph
Design Speed (if know):__________ mph
Expected Future Change in ADT=_______ Percent/yr. Or _____ Percent in _____years
Utility Pole Location (one side or two):_____________________________

	No. of Poles	Pole Spacing	Pole/Mile	Avg. Pole Offset form Edge of Through Line
Side 1:	________	___________ ft	___________	_______________ ft
Side 2:	________	___________	___________	_______________ ft
Total:	________		___________	_______________ ft

<u>Type of Utility Poles and Lines:</u>

Side 1	Side 2 (if applicable)	
________	________	Wood telephone poles
________	________	Wood dower poles carrying <69 KV lines
________	________	Non-wood poles
________	________	Heavy wood distribution and transmission poles
________	________	Steel transmission poles

Roadside Coverage Factor – An estimate of the coverage of fixed objects within 30 feet (9 m) from the edge of pavement or curb face. The rules in counting objects are as follows:

1. Two point objects within 10 feet (3 m) of each other are counted as one point object.
2. Continuous objects are represented by their cumulative length along the section
3. If any object is screened by another point or continuous object and cannot be struck, it should not be count
4. When both point and continuous fixed-object are present the coverage factors are added.
5. The maximum roadside coverage factor is 100 percent.
6. Minor fixed objects that do not usually result in a reported accident when struck are not counted. The guidelines on which object to count are as follows:

<u>Count</u>	<u>Do not count</u>
Most signs (see exception at right)	Delineators
Luminaire supports	Small signs on single metal channels
Trees greater than 4 inches (10 cm) diameter	Breakaway signs
Multiple or massive mail boxes	Small single-post mailboxes
Culvert headwalls	Trees less than 4 inches (10 cm) diameter
Bridge columns and abutments	Brush
Fences	Objects shadowed by guardrail
Rock outcropping	Utility poles
Rock cuts	
Guardrail	
Concrete barriers	
Other	

Total point Objects__________________
Total Length of Continuous Object (ft.) __________________

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM B: Countermeasure Description

(complete Form B for Each Countermeasure)

Countermeasure Number______ of ______.
Countermeasure to be evaluated (Check One):

_______ Placement of Utility Lines Underground (Check One)

- _______ Telephone lines
- _______ Electric distribution lines <69 KV, direct bury, one phase
- _______ Electric distribution lines <69 KV, direct bury, three phase
- _______ Electric distribution lines <69 KV, , conduit
- _______ Electric transmission lines <69 KV
- _______ Other: ________________________________

_______Pole Relocation from _____ feet to _____ feet from the edge of the pavement

_______ Increase Pole Spacing from____ to____ feet. Thus the total number of poles on the section will be______ which translates to _______ poles per mile of roadway section.

_______ Pole relocation from _____feet to _____ feet from the edge of the roadway and Increase Pole Spacing to _______ feet which translate to ______ poles per mile of roadway section.

_______ Add Breakaway Pole Feature to _______ percent of poles.
Expected reduction in injury and fatal accidents = _________ %.

_______ Multiple Pole use (for a section with utility poles on both sides of the roadway) by removing utility lines from the line of poles closest to the roadway. The average offset of the remaining line of utility pole is ____ feet from the edge of the roadway. The number of poles on the section would be translating to ____ poles per mile of section.

Expected change in annual maintenance cost (total section):

- _______ No change
- _______ Increase of $ __________________ per year
- _______ Decrease of $ _______________ per year
- _______ Unknown (assume $0 change in unknown)

Expected initial project costs (Specify):

- $ _________ per Mile: ____
- $ _________ Per Pole: ____
- $ _________ Total: ____

Expected countermeasure service life = ________________________________ years (assume 20 years if unknown)

Interest rate = _____ percent per year (assume 12 percent if unknown)

APPENDIX B

STATE OF FLORIDA COUNTIES CODE

Table B1.: The list of seven district and the sixty-seven counties in Florida (cd# = code number).

District 1	cd#	District 2	cd#	District 3	cd#	District 4	cd#	District 5	cd#	District 6	cd#	District 7	cd#
Charlotte	1	Alachua	26	Bay	46	Broward	86	Brevard	70	Dade	87	Citrus	2
Collier	3	baker	27	Calhoun	47	Indian River	88	Flagler	73	Monroe	90	Hernando	8
Desota	4	Bradford	28	Escambia	48	Martin	89	Lake	11			Hillsborough	10
Glades	5	Clay	71	Franklin	49	Palm beach	93	Marion	36			Pasco	14
Hardee	6	Columbia	29	Gadsden	50	St. Lucie	94	Orange	75			Pinellas	15
Hendry	7	Dixie	30	Gulf	51			Osceola	92				
Highlands	9	Duval	72	Holmes	52			Seminole	77				
Lee	12	Gilchrist	31	Jackson	53			Summer	18				
Manatee	13	Hamilton	32	Jefferson	54			Volusia	79				
Okeechobee	91	Lafayette	33	Leon	55								
Polk	16	Levy	34	Liberty	56								
Sarasota	17	Madison	35	Okaloosa	57								
		Nassau	74	Santa Rosa	58								
		Putnam	76	Wakulla	59								
		St. Jones	78	Walton	60								
		Suwannee	37	Washington	61								
		Taylor	38										
		Union	39										

Source: Florida Department of Transportation

APPENDIX C

STATE OF FLORIDA CLEAR ZONE POLICY

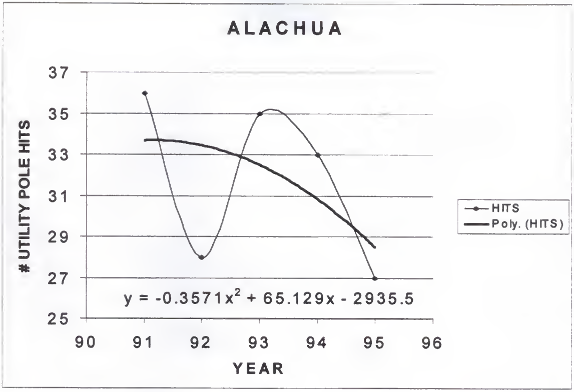
Table C1: FDOT Clear Zone Policy

CLEAR ZONE									
RURAL						URBAN			
Design Speed	Freeway Arterial &Collector ADT ≥ 1500		Arterial & Collector ADT ≤ 1500		Collector & Local ≤ 45 mph	Arterial Collector no C/G		Arterial Collector C/G
	Travel	Auxiliary	Travel	Auxiliary		Travel	Auxiliary	
65 Design Min.	 36 30	 24 18	 30 24	 18 14				
55 Design Min.	 30 24	 18 14	 24 18	 14 14				
50 Design Min.	 24 18/10	 14 18/10	 20 14	 14 14		 24 18	 14 10	
45 Design Min.	 24 18/10	 14 18/10	 20 14	 14 14	 14 10	 24 18/10	 14 10	 4 2.5
40 Design Min.					 14 10	 18 14/10	 10 6	 4 2.5
30 Design Min.					 14 10	 18 14/10	 10 6	 4 2.5

Source: Florida Department of Transportation.

APPENDIX D

TREND ANALYSIS



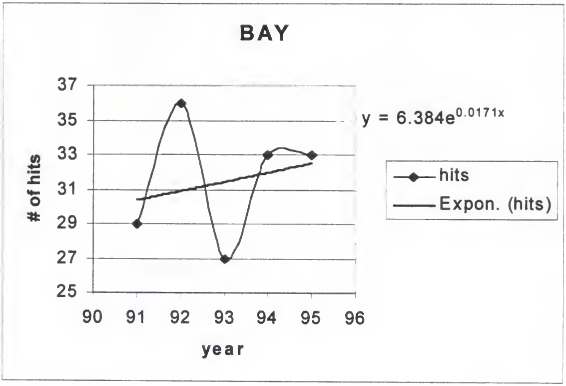
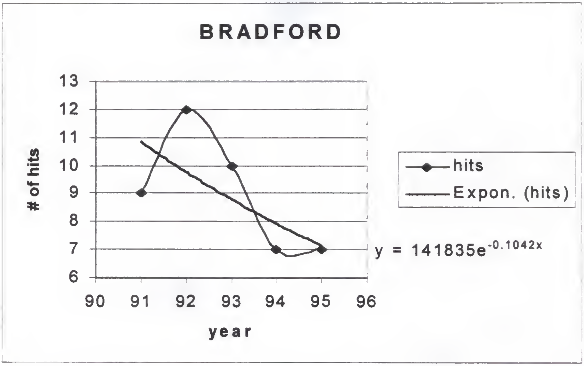


Figure D.1: Total accidents vs. time (year) for Alachua and Bay Counties.



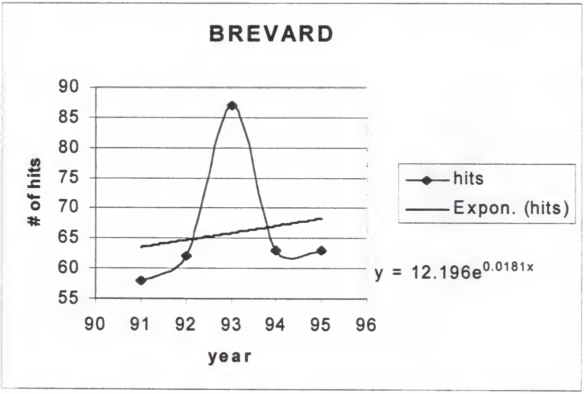
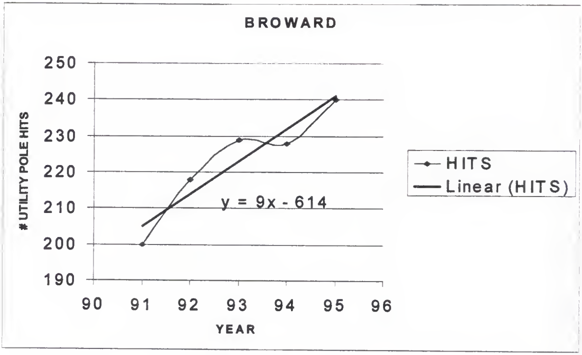


Figure D.2: Total accidents vs. time (year) for Bradford and Brevard Counties.



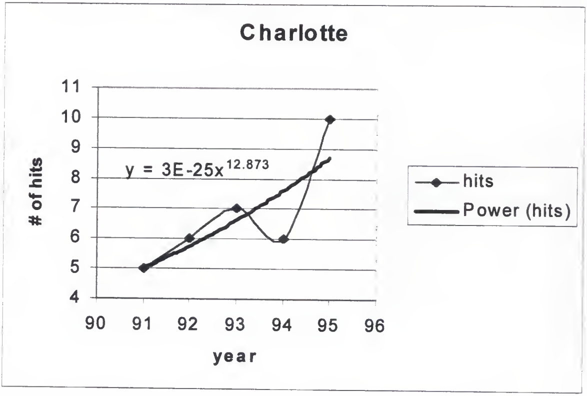
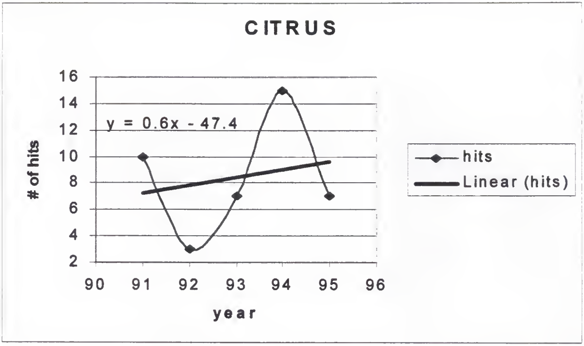


Figure D.3: Total accidents vs. time (year) for Broward and Charlotte Counties.



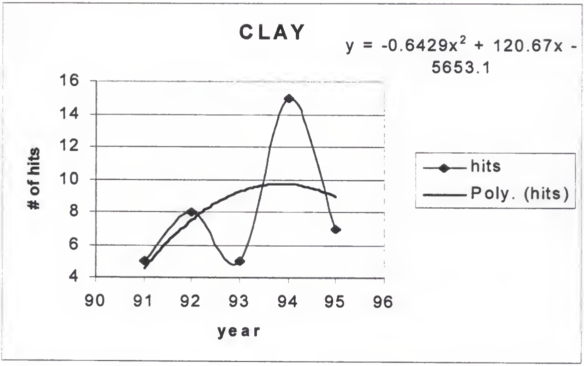
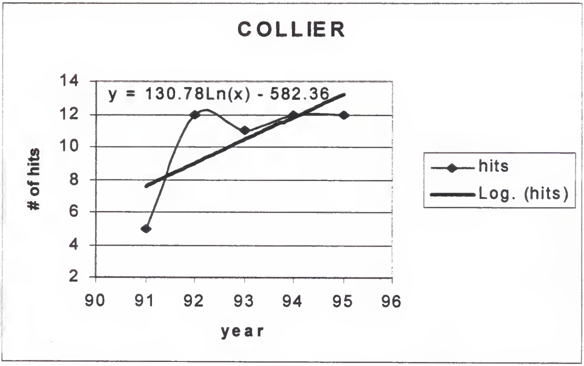


Figure D.4: Total accidents vs. time (year) for Citrus and Clay Counties.



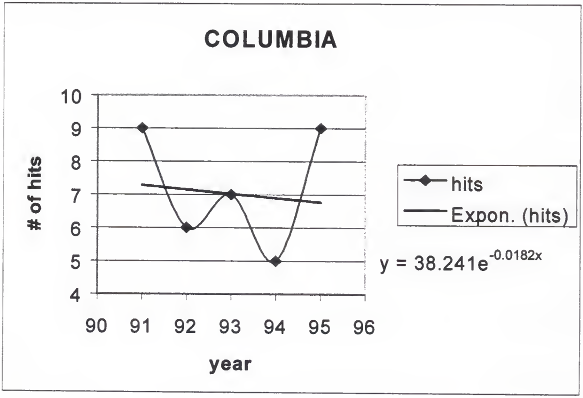
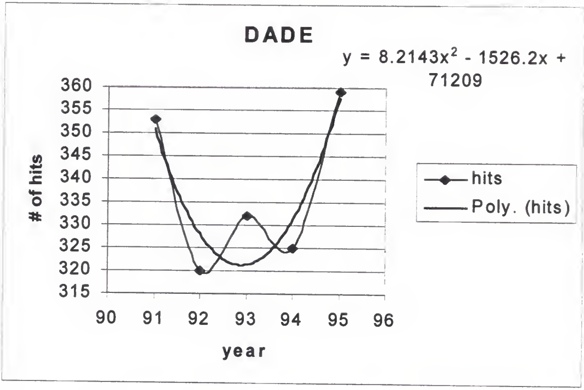


Figure D.5: Total accidents vs. time (year) for Collier and Columbia Counties.



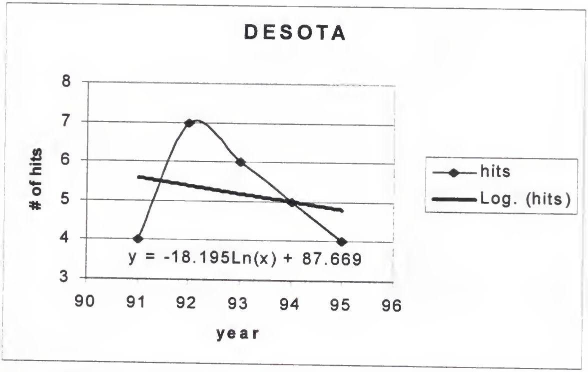
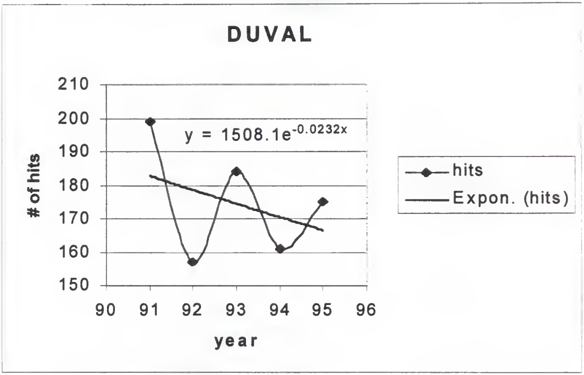


Figure D.6: Total accidents vs. time (year) for Dade and Desota Counties.



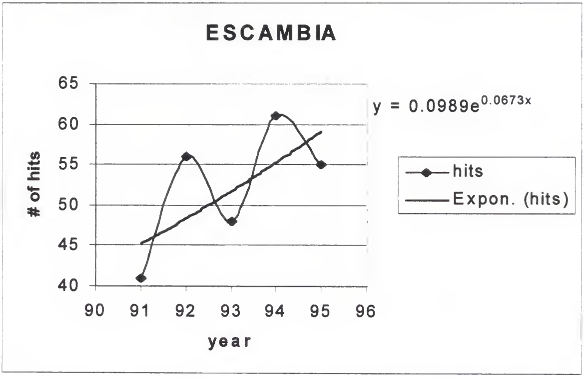
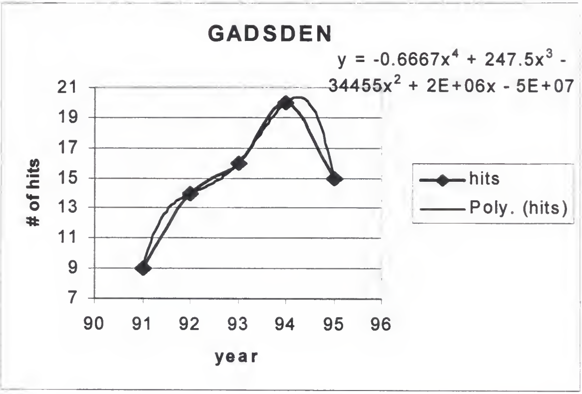


Figure D.7: Total accidents vs. time (year) for Duval and Escambia Counties.



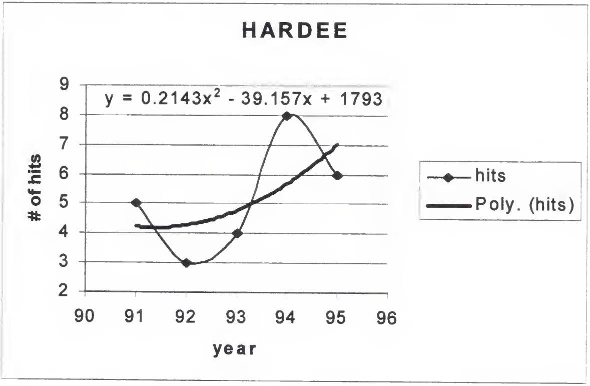
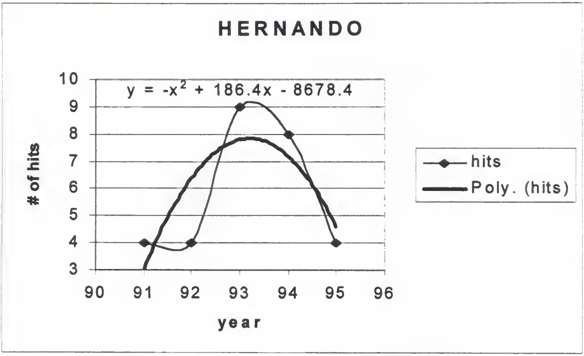


Figure D.8: Total accidents vs. time (year) for Gadsden and Hardee Counties.



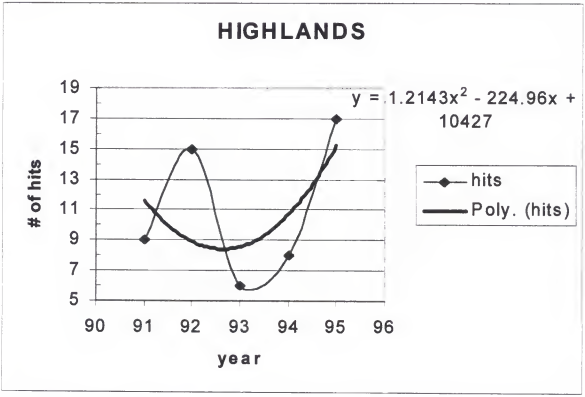
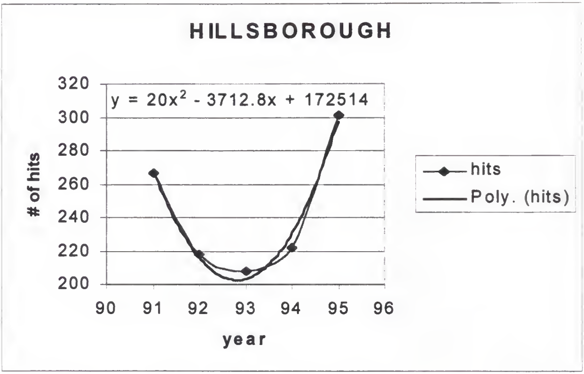


Figure D.9: Total accidents vs. time (year) for Hernando and Highland Counties.



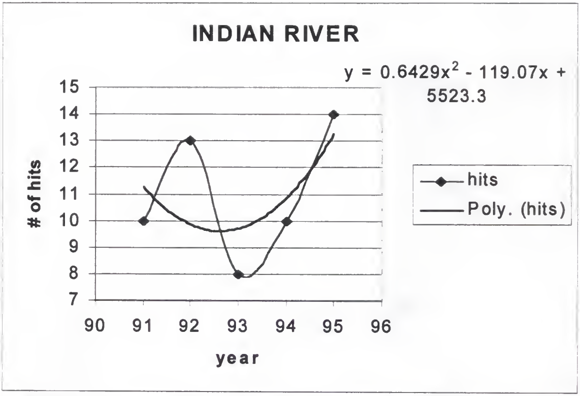
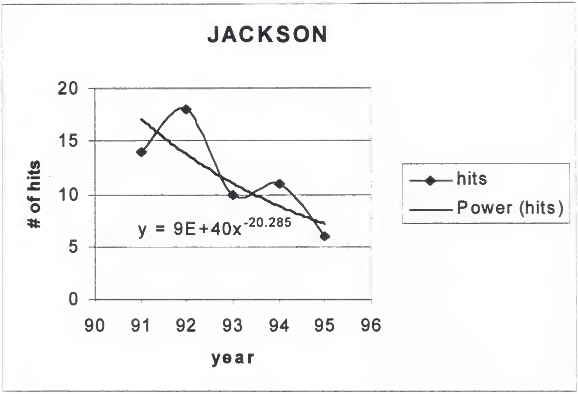


Figure D.10: Total accidents vs. time (year) for Hillsborough and Indian River Counties.



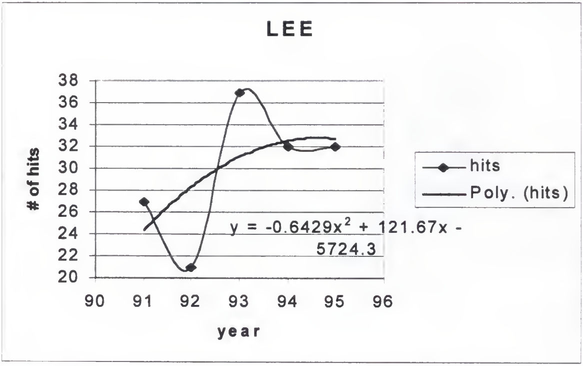
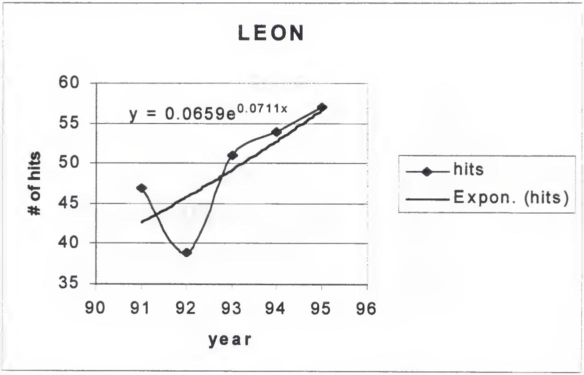


Figure D.11: Total accidents vs. time (year) for Jackson and Lee Counties.



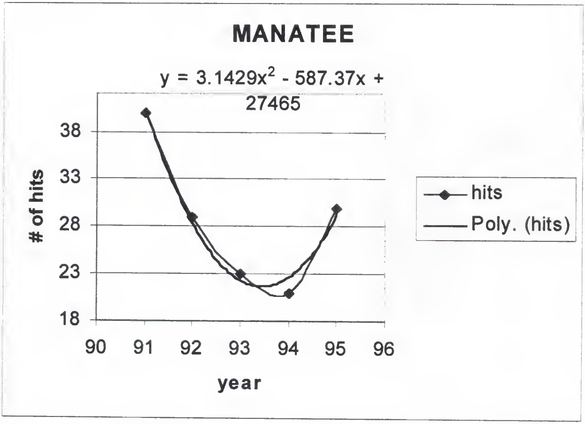
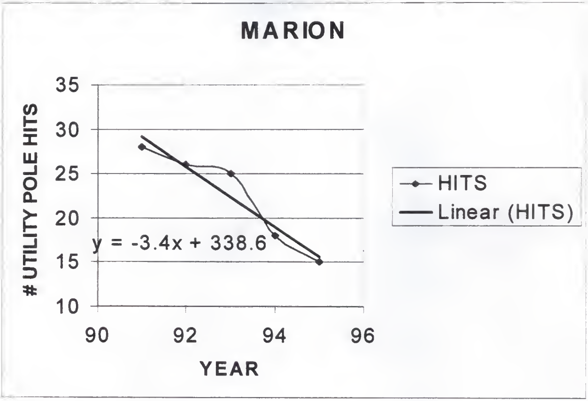


Figure D.12: Total accidents vs. time (year) for Leon and Manatee Counties.



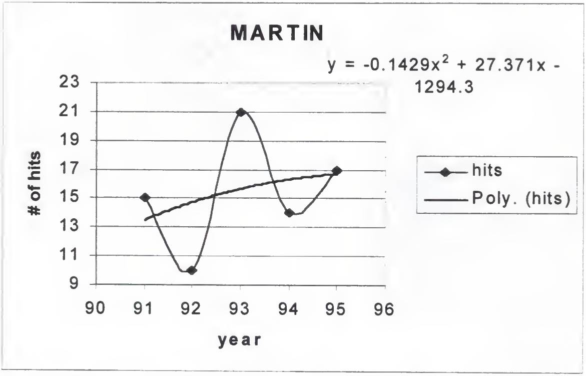
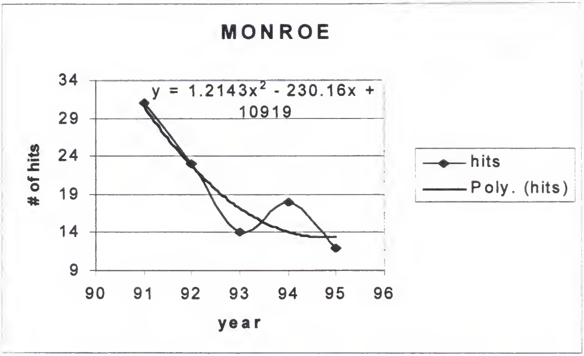


Figure D.13: Total accidents vs. time (year) for Marion and Martin Counties.



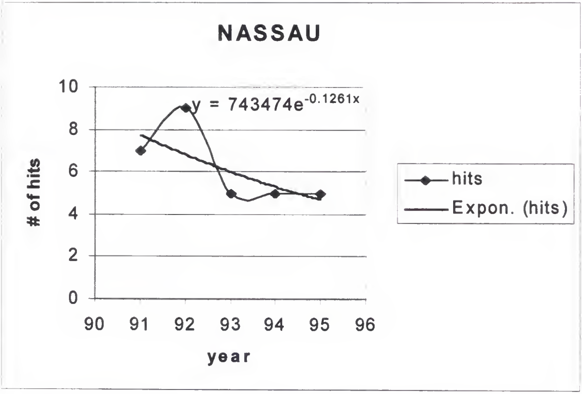
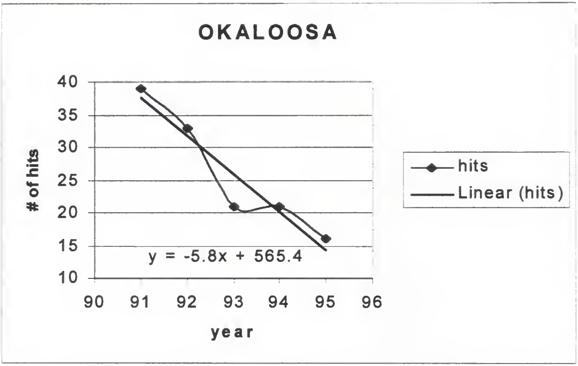


Figure D.14: Total accidents vs. time (year) for Monroe and Nassau Counties.



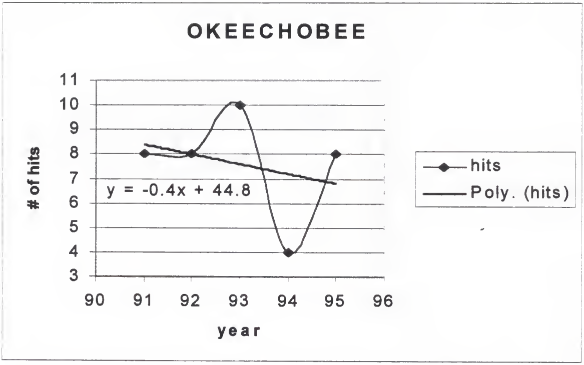
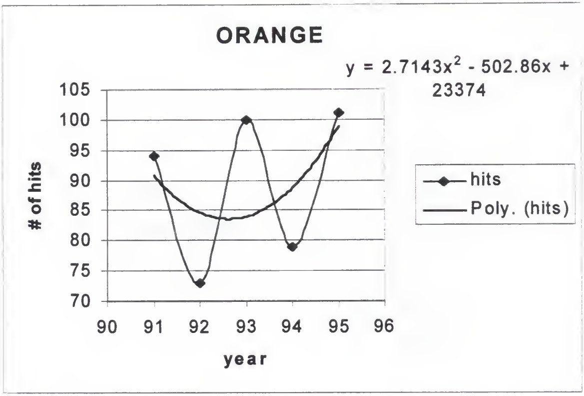


Figure D.15: Total accidents vs. time (year) for Okaloosa and Okeechobee Counties.



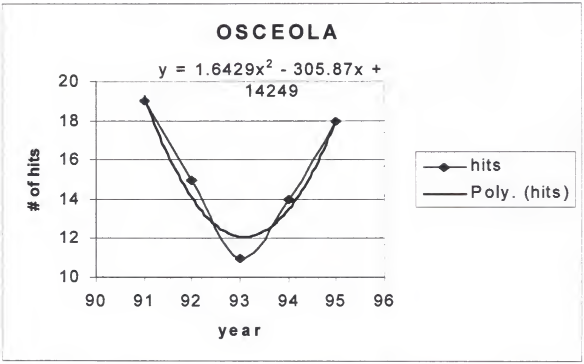
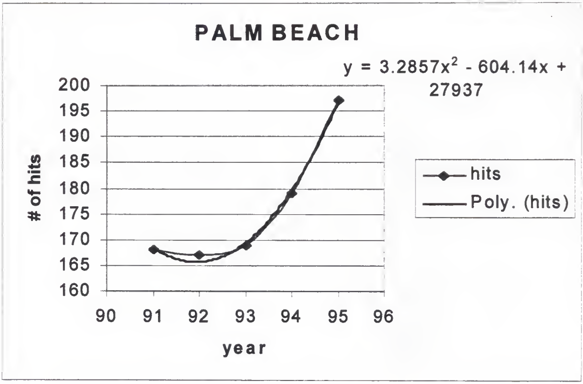


Figure D.16: Total accidents vs. time (year) for Orange and Osceola Counties.



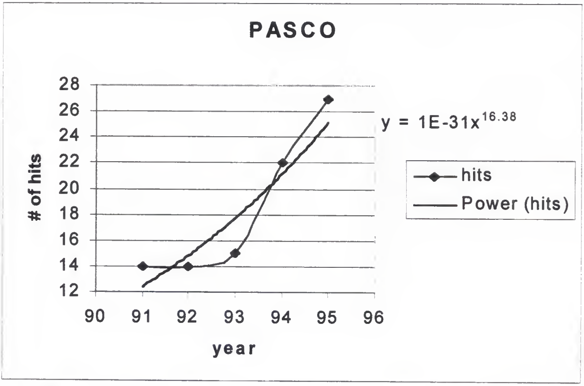
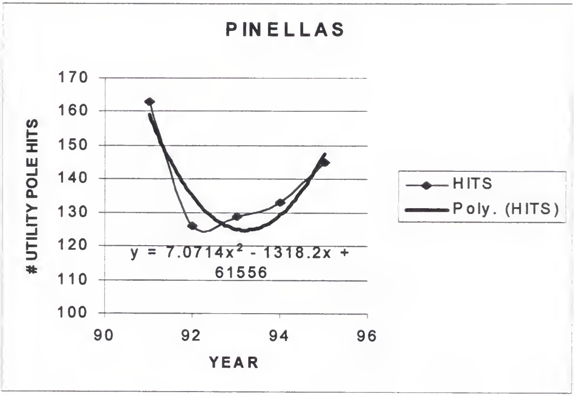


Figure D.17: Total accidents vs. time (year) for Palm Beach and Pasco Counties.



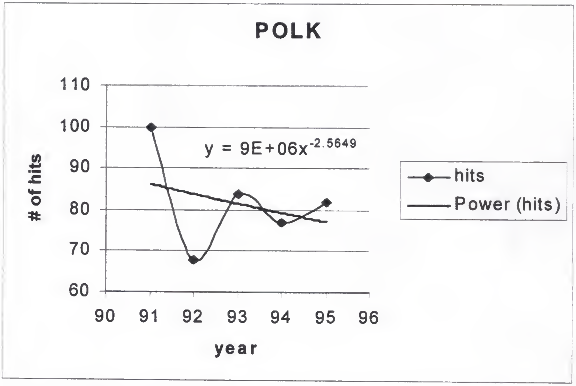
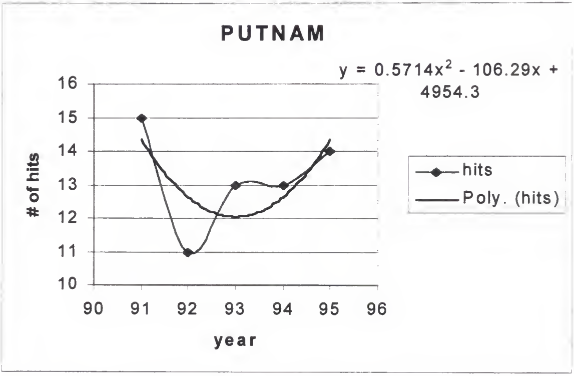


Figure D.18: Total accidents vs. time (year) for Pinellas and Polk Counties.



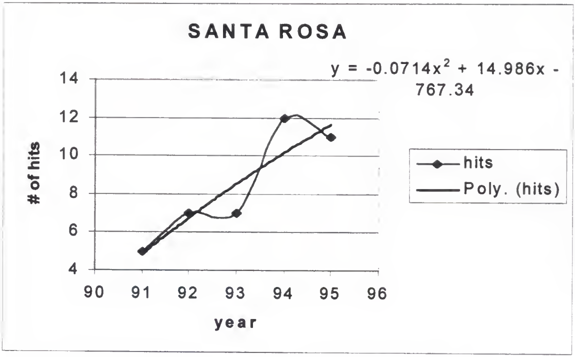
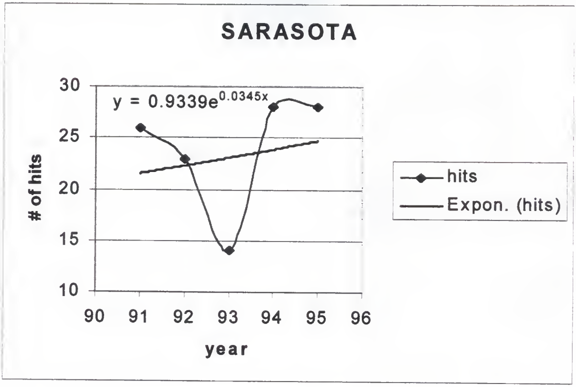


Figure D.19: Total accidents vs. time (year) for Putnam and Santa Rosa Counties.



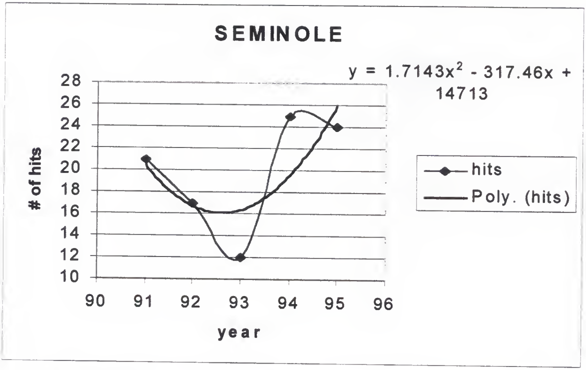
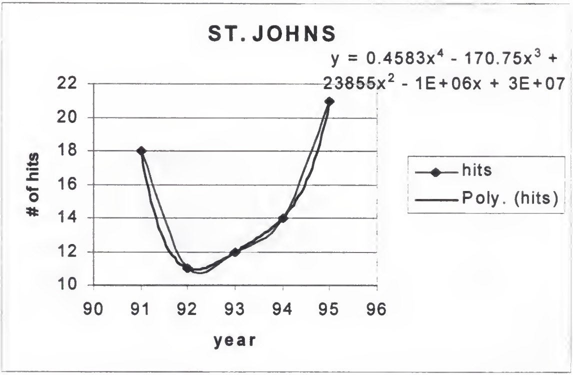


Figure D.20: Total accidents vs. time (year) for Sarasota and Seminole Counties.



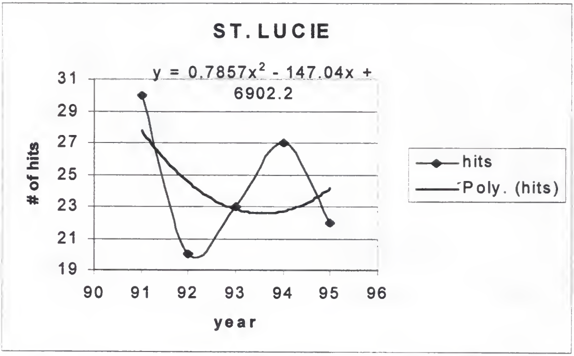
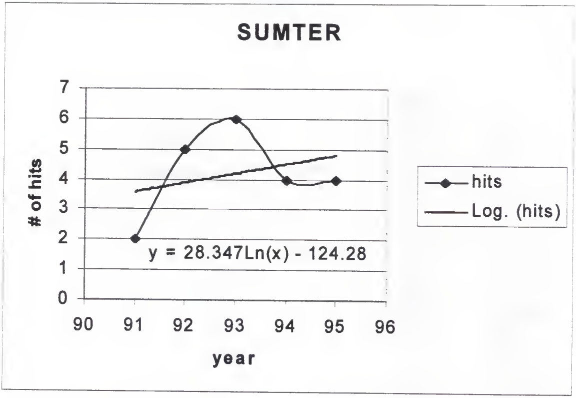


Figure D.21: Total accidents vs. time (year) for St. Johns and St. Lucie Counties.



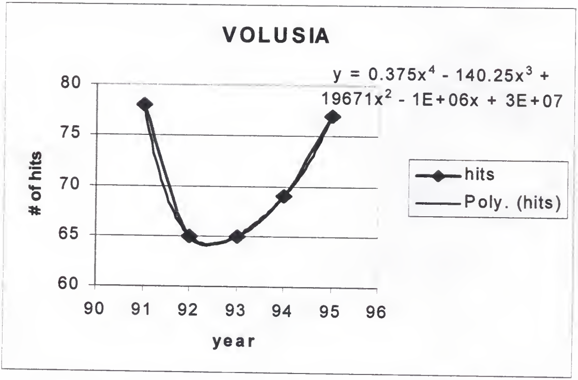


Figure D.22: Total accidents vs. time (year) for Sumter and Volusia Counties.

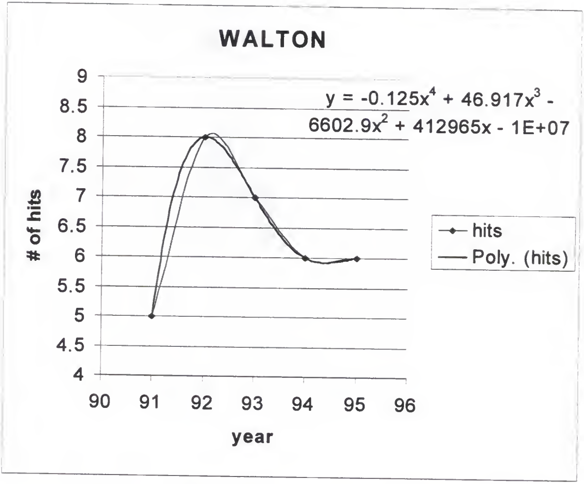


Figure D.23: Total accidents vs. time (year) for Walton County.

REFERENCES

1. AASHTO, "A policy on The Accommodation of Utilities Within Freeway Right-of-Way," American Association of State Highway and Transportation Officials, Washington, D.C., February 1989.

2. AASHTO, "HIGHWAY Safety Strategic Plan for 1991-2000," American Association of State Highway and Transportation Officials, Washington, D.C., February 1990.

3. Agresti, A., " An Introduction to Categorical Data Analysis," John-Wiley, New York, 1996.

4. Agresti, A., "Categorical Data Analysis," John Wiley, New York, 1990.

5. Anderson, T.W., "An Introduction to Multivariate Statistical Analysis," John Wiley, New York, 1984.

6. Baily, A. Graham, "Accident Costs--Are We using Them Correctly?," Technical Advisory T 7570.1, USDOT, FHWA, June 30, 1988.

7. Beck, V. James, and Arnold, J. Kenneth, "Parameter Estimation in Engineering and Science," John-Wiley, New York, 1977.

8. Bhesania, Russi P. "Using Accident Statistics and Characteristics to Improve Safety." Institute of Transportation Engineering Journal, v61 March 1991, 37-41.

9. Box, P. G. and Draper, N.R., "Empirical Model-Building and Response Surfaces," John Wiley, New York, 1987.

10. Casella, G. and Berger L. R., "Statistical Inference," Wadsworth & Brook/Cole, California, 1990.

11. Cheng, Yue-Jeh. "Improved Convergence in Traffic Accident Simulation Using Expert System Techniques." 1996.

12. Cirillo, J. A. and Council, F. M. "Highway Safety: Twenty Years Later," Transportation Research Record 1068, pages 90-95, Washington, D.C., 1990.

13. Department of Highway Safety & Motor Vehicles, "Florida Traffic Accident Facts." 1988.

14. Department of Highway Safety & Motor Vehicles, "Florida traffic Crash Facts." 1989-90.

15. FDOT, "Utility Accommodation Guide," Florida Department of Transportation, Decumbent No. 710-020-001-b, May 1990.

16. FHWA, "Guide to Safety Features for Local Roads and Streets," U.S. Department of Transportation, FHWA report, Washington, D.C.

17. FHWA, "Highway/Utility Guide," U.S. Department of Transportation, FHWA report, Publication No. FHWA-SA-93-049, Washington, D.C., June 1993.

18. FHWA, "Local Highway Safety Improvement Program--User's Guide," U.S. Department of Transportation, FHWA report, Washington, D.C., July 1986.

19. FHWA, "Motor Vehicle Accident Costs," Technical Advisory T 7570.1, FHWA, U. S. Department of Transportation, Washington, D. C. , June 1988.

20. FHWA, "Statistical Programs: A Customer's Guide to Using Highway Statistics." Washington, D. C.: U. S. Department of Transportation, Federal Highway Administration, 1996.

21. FHWA, "Summary of Utility Pole Fatalities by State, 1990-1993," Florida Division Office, FHWA, USOT, January 9, 1995.

22. Fildes, B. N. and Lee, S. J., "The Speed Review: Road Environment, Behavior, Speed Limits, Enforcement and Crashes." Office of Road Safety, Australia, 1993.

23. Florida Public Service Commission, "Report on Cost-Effectiveness of Underground Electric Distribution Facilities," Tallahassee, Florida, December 1991.

24. Florida Public Service Commission, "Cost-Effectiveness of Undergrounding Electric Utility Wiring," A Report to the Florida Legislature, Tallahassee, Florida,1991.

25. Fox, J. C., Good, M. C., Joubert, P. M., "Collisions with utility Poles – A Summary Report," University of Melbourne, Commonwealth Department of Transport, February 1979.

26. Frisbie, T. "Safer Roadsides for Smaller Cars," Traffic Safety, May-June 1989.

27. Gittings, G. L. and Jacobs, D. J. "Evolution of Risk Management in a State Highway Agency," Transportation Research Circular Number 361, Washington, D. C., July 1990.

28. Graf, N. L., Boos, J.V., Wentwogth, J. A., "Single Vehicle Accidents Involving Utility Poles," Transportation Research Report No. 571, Washington D. C., 1976.

29. Graham, J. L., Harwood, D. W., "Effectiveness of Clear Recovery Zones," NCHRP Report 247, Transportation Research Board, May 1982.

30. Griffin, L. I., "Probability of Driver Injury in Single Vehicle Collisions with Roadway Appurtenances as a Function Passenger Car Curb Weight," Texas Transportation Institute, Texas A&M University System, October 1981.

31. Hadi, M. A., "Estimate the Safety Effects of Cross Section Design for Various Highway Type Using Negative Binomial Regression." Submitted to TRB for Presentation in 74 Annual Meeting, Washington D. C. January 1995. Unpublished.

32. Hall, J. W., Burton, C. J., Coppage, D. G., Dickinson, L. V., "Roadside Hazards on Non-Freeway Facilities," University of Maryland, Transportation Research Record No. 601, Washington D. C., 1976.

33. Hamburg, Morris "Introduction to the Practice of Statistics," 4th edition, University of Pennsylvania, San Diego, New York, Chicago, Austin, London, Sydney, Tokyo, Toronto, 1989.

34. Hosmer, D. W., "Applied Logistic Regression," John Wiley, New York , 1989.

35. Insurance Institute for Highway Safety, "Roadside Hazard, Fatality Facts 1991," Arlington, Virginia, July 1991.

36. Johansson, G. and Rumar, K., "Drivers' Brake Reaction Times," Human Factors, 13, 1971. Pp. 23-27

37. Jones, I. S. and Baum, A. S. "An analysis of the Urban Utility Pole Problem," Calspan Field Services, Inc., Federal Highway Administration, December 1980.

38. Kasprzak, W., Bertold Lysik and Marek Rybaczuk, "Dimensional Analysis in the Identification of Mathematical Models," Technical University of Wroctaw, Poland, World Scientific, 1990.

39. Kleinbaum, G. David, Kupper, L. Lawrence, and Muller, E. Keith, "Applied Regression Analysis and other Multivariable Methods," PWS-KENT, Boston, 1988.

40. Kopperman, S., "Utility Pole Accident Countermeasures Evaluation Program and Input Processor-Users Manual," FHWA, USDOT, December 1986.

41. Kragh, B. C. , Miller, T. R. and Reinert, K. A. "Accident Costs for Highway Safety Decision Making," Public Roads, Vol.50, No. 1, 1986. pp. 15-20.

42. Kurth, Rudolf "Dimensional Analysis and Group Theory in Astrophysics," Southern Illinois University, Edwardsville, 1972.

43. Lackey, S. and Love, J. "Utility Relocation Policy," Public Works, v121 n6 May 1990, 65-66.

44. Lau, Michael Yiu-Kuen. "Accident Prediction Model Development: Signalized Intersection." Berkeley, CA: Institute of Transportation Studies, University of California, 1988.

45. Lerner, N., Ratte, D., Huey, R., McGee, H. and Hussain, S., "Older Driver Perception Reaction Time: Literature Review," Unpublished. Washington, D. C., Federal Highway Administration, 1990.

46. Lerner, N., Huey, McGee, H. and Sullivan, A., "Older Driver Perception Reaction Time for Intersection Sight Distance and Object Detection," Volume I: Final Report. USDOT, FHWA-RD-93-168, 1995.

47. Lindly, J. K. and Turner, D. S. "Identification of Typical Highway-Utility Interaction Problems and Potential Solutions," Transportation Research Record 1326, Washington, D.C., 1991.

48. Liu, G. X., "A Study of Traffic Safety and Vehicle Travel Speed in Sask." Research Report for Sask. Highways & Transportation, University of Regiona, Faculty of Engineering, 1996

49. Liu, G. X., "Relationship Between Vehicle Travel Speed and Traffic Collisions in Sakatchewan," Canadian Society for Civil Engineering, Edmonton, Albereta, May 29 to June 1, 1996. Vol. IIIa. Pp.411-422.

50. Mak, K. K., Mason, R. L., "Accident analysis-- Breakaway and Non-breakaway Poles Including Sign and Light Standards Along Highways," FHWA, August 1980.

51. McLean, VA "Accident Data Analysis of Side Impact, Fixed Object Collisions." U. S. Federal Highway Administration; Springfield, VA: National Technical Information Service, 1994.

52. Mclean, V. A, T. Miller, J. Viner, S. Rossman, N. Pindus, and W. Gallert, " The costs of Highway Crashes–Final Report, August 1985 – May 1991," USDOT, FHWA, Washington, D.C., October, 1991.

53. Miaou, Shaw-Pin and Lum, Harry. "Modeling Vehicle Accidents and Highway Geometric Design Relationships." Accident Analysis and Prevention, v25 n6 Dec. 1993, Pp 689-709.

54. Mishan, E. J. "Cost-Benefit Analysis, New and Expanded Edition," Praegers Publishers, New York, 1976.

55. Montgomery, C. Douglas and Peck, A. Elizabeth, "Introduction to Linear Regression Analysis", John-Wiley, New York, 1992.

56. Moore, Davis S. and McCabe, George P. "Introduction to the Practice of Statistics," Purdue University, New York, 1989.

57. Myers, R. H., "Classical and Modern Regression with Applications," 2nd Edition, PWS-Kent, Boston, Massachusetts, 1990.

58. National Safety council, "Estimating the Cost of Accidents," Chicago, Illinois, 1990.

59. National Highway Traffic Safety Administration, "The Economic Cost of Motor Vehicle Crashes, 1990" Washington, D. C., U. S. Department of Transportation, 1993.

60. National Highway Traffic Safety Administration, "National Accident Sampling System Crash Worthiness Data System," 1988-1990." Washington, D. C., U. S. Department of Transportation, 1994.

61. National Technical Information Service, "Special Study: Motor Vehicle Collision with Trees Along Highways, Roads, and Streets: An Assessment." Washington, D. C., Springfield, VA, 1981.

62. Nordhoff, Larry S. "Motor Vehicle Collision Injuries: Mechanisms, Diagnosis, and Management." Gaithersburg, MD: Aspen Publishers, 1996.

63. Pilkington II, G. B. "Utility Poles: A Highway Safety Problem." Public Roads, Volume 52, number 3, December 1988.

64. Poch, M. and Mannering, F., "Negative Binomial Analysis of Intersection Accident Frequencies," Transportation Research Board, Washington D. C., January, 1996.

65. Post, E.R. " Feasibility Study of Breakaway Stub Concept for Wooden Utility Poles," Final Report, for Federal Highway Administration, August, 1982.

66. "Roadside Design Guide," American Association of State Highway and Transportation Officials, Washington, D. C., 1988.

67. SAS/STAT Software "Changes and Enhancements through Release 6.12," SAS Institute Inc., Cary, North Carolina, 1997.

68. Seber, G. A. F. and Wild, C. J., "Nonlinear Regression," John Wiley, New York, 1989.

69. Shank, V., F. Mannering, and Barfield W., "Effect of Roadway Geometric and Environmental Factors on Rural Accident Frequencies," Forthcoming in Accident Analysis and Prevention, 1995.

70. Sliogeris, J., "100 km Peer Hour Speed Limit-Evaluation of Road Safety Effects." Road Safety Division, Vic. Roads, KEW Vic 3101, Melbourne, Australia, 1992.

71. Steel, G. D. Robert and Torrie, H. James, "Principles and Procedures of Statistics, McGraw-Hill, New York, 1980.

72. Sugden, Robert and Williams, Alan, "The Principles of Practical Cost-Benefit Analysis," Oxford University Press, 1978.

73. Taylor, E., "Dimensional Analysis for Engineers," Clarendon Press, Oxford, 1974.

74. Texas Transportation Institute, "Risk management to Reduce Tort Liability: A Short Course," College Station, Texas, 1985.

75. Thuesen, G. J. and Fabrycky, W. J. "Engineering Economy," Seventh Edition, Prentice Hall, Englewood Cliffs, N.J. 07632.

76. Transafety Reporter, "Hazardous Highway Surface Near Roadside Utility Structures Results in Two Million Cases," Vol. II, No. 11, Washington, D.C., 1983

77. Transafety Reporter, "Utility Pole Placement and Liability--Two New Cases," Vol. II, No. 7., Washington, D.C., July 1984.

78. Transportation Research Board # 106, "Practical Guidelines for Minimizing Tort Liability Washington, D.C., December 1983.

79. Transportation Research Circular Number 362, "Use of Benefit-Cost Analysis to Develop Roadside Safety Policies and Guidelines," Washington, D.C., August 1990.

80. TRB, "Practical Guidelines for Minimizing Tort Liability," Transportation Research Board # 106, Washington, D. C., December 1983.

81. Turner, D. S. "A Primer on the Clear Zone," Transportation Research Record 1122, Transportation Research Board, National Research Council, Washington, D.C., 1987.

82. Turner, D. S., Davis, J. K. and Wood, B. T. , "Status Report: Tort Liability Among State Highway Agencies," Transportation Research Circular Number 361, Washington, D.C., July 1990.

83. Wattleworth, J. A., Atherely, R. J., Hsu, P., "Accident Reduction Factors For Use in California Benefit/Cost," Technical report, prepared for FDOT and FHWA, September 1988.

84. Winer, B.J. , Brown, R.D., and Michels, M. K., "Statistical Principles in Experimental Design, McGraw-Hill, New York, 1991.

85. Winfrey, Robley "Economic Analysis for Highways," International Textbook Company, Pennsylvania, 1969.

86. Zegeer, C. V., "Highway Safety Improvement Program- User's Manual," Prepared by Goodell-Grivas, Inc. for FHWA, January 1981.

87. Zegeer, C. V., Cynecki, M. J., "Selection of Cost -Effective Countermeasures For Utility Pole Accidents – Users Manual," Report Number FHWA-IP-86-9,Federal Highway Administration, December 1986.

88. Zegeer, C. V., Parker, M. R. "Cost–Effectiveness of Countermeasures for Utility Pole Accidents," FHWA Research Report, January 1983.

89. Zegeer, C. V., Reinfurt, D. W., Hummer, J., Herf, L. and Hunter, W., "Safety Effects of Cross-Section Design for Two-Lane Roads," Transportation Research Record 1195, Washington, D. C., 1995. PP. 20-32

90. Zegeer, Charles V. "Safety Effectiveness of Highway Design Features." McLean, VA: Federal Highway Administration, Design Concepts Research Division, 1992.

91. Zegeer, C. V. , Stewart, R. , Council, F., and Neuman, T. R., " Roadway Widths for Low Traffic Volume Roads," National Cooperative Highway Research Program Report No. 362, Transportation Research Board, National Research Council, Washington, D. C. , 1994.

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After receiving his Bachelor of Science degree in Electrical Engineering from Louisiana State University in August 1988, Mohammad Habibi joined the Department of Mathematics at the University of Florida and received a Master's degree in applied mathematics in May 1990. He taught at the University of New Orleans and Southern University, State of Louisiana, from 1991 to 1992.

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In August 1996, Mohammad started his doctoral program in the department of Civil Engineering at the University of Florida. Due to his background and interest in applied mathematics and statistics, he became involved in developing utility pole accident rate predictive model presented in this research work.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Associate Professor of Civil Engineering

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